MCDONNELL DOUGLAS TECHNICAL SERVICES CO.
HOUSTON ASTRONAUTICS DIVISION

SPACE SHUTTLE ENGINEERING AND OPERATIONS SUPPORT

DESIGN NOTE NO. 1.4-7-30

ORBITER/CARRIER SEPARATION FOR THE ALT FREE FLIGHT #1 REFERENCE TRAJECTORIES

MISSION PLANNING, MISSION ANALYSIS AND SOFTWARE FORMULATION

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1 MARCH 1976

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TAILCONE OFF ORBITER CONFIGURATION

GLOSSARY

ALT	APPROACH AND LANDING TEST
cg	CENTER OF GRAVITY
JSC	JOHNSON SPACE CENTER
KCAS	KNOTS CALIBRATED AIRSPEED
KEAS	KNOTS EQUIVALENT AIRSPEED
L_B	VEHICLE BODY LENGTH
MDTSCO	MCDONNELL DOUGLAS TECHNICAL SERVICES COMPANY
MPAD	MISSION PLANNING AND ANALYSIS DIVISION

1.0 SUMMARY

Separation trajectories of the carrier and orbiter for the tailcone off and tailcone on orbiter configurations are required to support the JSC MPAD generation of reference trajectories for ALT free flight #1. This report documents the details of the generation of the separation trajectories. The analysis culminated in the MDTSCO definition of separation trajectories between physical separation and orbiter/carrier vortex clearance.

The requirement for this analysis is elaborated upon in Section 2.0. The specifications, assumptions and analytical approach used to generate the separation trajectories are presented in Section 3.0. The results of the analytical approach are evaluated in Section 4.0. Conclusions and recommendations are summarized in Section 5.0. Supporting references are listed in Section 6.0.

2.0 INTRODUCTION

Separation trajectories of the carrier and orbiter are required to support the JSC MPAD generation of reference trajectories for ALT free flight #1 (see Reference 1). The separation trajectories encompass the flight time duration between physical separation of the orbiter from the carrier and ALT interface attainment by the orbiter in order to assure carrier vortex avoidance. Toward that end this MDTSCO "Orbiter/Carrier Separation for the ALT Free Flight #1 Reference Trajectories" is performed for both the tailcone off and tailcone on orbiter configurations.

3.0 DISCUSSION

This section summarizes the specifications, assumptions and analytical approach used in this analysis. Maximum utilization of previous analyses is made in order to expedite definition of separation trajectories of the orbiter from the carrier. Source data is referenced accordingly in the subsequent text.

In this analysis, the ALT orbiter/carrier separation is simulated by the Space Vehicle Dynamics Simulation in two flight phases. The orbiter/carrier separation flight conditions constitute the initial conditions of the separation flight phase. The separation flight phase is defined to be five seconds in duration. The post separation flight phase is defined to be initiated at five seconds after physical separation of the orbiter from the carrier and to terminate at a point sufficient to demonstrate orbiter avoidance of the carrier vortex.

3.1 Specifications

The specifications for the separation trajectories follow.

1) Orbiter/carrier separation design criteria and constraints:

   a) Separation clearance distance between the cg's of the respective vehicles (as measured in the carrier reference coordinate system at 4 sec after separation) must exceed 140 ft.

   b) Relative normal acceleration at separation between the respective vehicle centers of mass (as measured in the carrier reference coordinate system) must approximate .75 g's.

   c) Initial pitch acceleration of the orbiter at separation must approximate 4 deg/sec^2.

   d) Normal load factor of the orbiter during the separation flight phase must not exceed 2 g's.

2) Orbiter/carrier post separation design criteria and constraints:

   a) The minimum path distance (between the current orbiter cg position and the flight path of the carrier cg) must exceed 140 ft when the time rate of change of minimum path distance remains positive (vortex avoidance).

   b) Carrier airspeed must not exceed 312 KCAS.

   c) Carrier normal load factor must not exceed 2 g's.

3) Orbiter ALT interface requirements:

a) Normal load factor of the orbiter must exceed .5 g's during the post separation flight phase.

b) Terminal flight path angle of the orbiter must approximate -27 deg and -18 deg for the tailcone off and tailcone on configurations, respectively (ALT interface).

3.2 Assumptions

Three categories of assumptions are used for this analysis. Category one entails the data base assumptions. Category two consists of the flight sequence assumptions. Category three contains assumptions pertinent to the analytical approach.

The data base assumptions follow.

1) Orbiter configuration:
   a) Tailcone off and tailcone on.
   b) Body flap at the 0 deg and -11.7 deg position for the respective tailcone configurations.
   c) Control system as defined in Reference 2.
2) Carrier configuration:
   a) Flaps retracted.
   b) Gear up.
   c) Control system as defined in Reference 3.
   d) Carrier engine thrust as defined in Reference 4.
3) Separation altitude and airspeed conditions as defined in Reference 5.
4) Freestream and proximity aerodynamics for both vehicles as defined in Reference 4.
5) Mass properties as defined in Reference 6.

The flight sequence assumptions are divided into two subcategories. The first subcategory is the separation flight phase sequence assumptions. The second subcategory is the post separation flight phase sequence assumptions.

The separation flight phase sequence assumptions follow.

1) Separation flight phase is defined to be 5 sec in duration.
2) Orbiter pitch rate command is maintained at 2 deg/sec for the first 3 sec and 0 deg/sec for the last 2 sec.
3) Carrier pitch attitude command is maintained in mated vehicle attitude hold for first 4 sec. Carrier pitch attitude command rate of 2.0 deg/sec is initiated at 4 sec and maintained until carrier equilibrium glide pitch attitude command is attained.
4) Carrier roll attitude command rate of -10 deg/sec is initiated at 2 sec and maintained until carrier bank angle of -30 deg is attained.
5) Carrier spoilers remain deployed.
6) Carrier thrust remains at idle.

The post separation flight phase sequence assumptions follow.

1) The time duration of the post separation flight phase is determined by the attainment of ALT interface by the orbiter.
2) The spoilers remain deployed.
3) The throttle remains at the idle position.
4) The carrier steering is a continuation of that initiated in the preceding flight phase.
5) Orbiter post separation steering for ALT interface attainment is initiated at 5 sec after separation.

Assumptions which simplify the analytical approach follow.

1) Only nominal data is assumed. No system nor environmental tolerances are analyzed.

2) Only the lightweight orbiter is analyzed (150,000 lbs, cg is 63.5% L_B).

3.3 Analytical Approach

The overall analytical approach consists of generating an orbiter/carrier separation reference trajectory for each of two orbiter tailcone configurations. Toward that end, a four step analytical approach common to both trajectories is used.

The first step is to determine the equilibrium glide conditions of the mated vehicle configuration at the termination of the preseparation pitchover maneuver. The mated trim program is used to determine the flight conditions required to maintain .75 g's relative normal load factor at separation and 4 deg/sec^2 post separation initial orbiter pitch acceleration at a prespecified incidence angle and altitude. Those flight conditions then constitute the initial conditions for the orbiter/carrier separation reference trajectories.

The second step is to calibrate the carrier pitch attitude which equilibrium glides the carrier at the separation airspeed during the post separation flight phase. That carrier pitch attitude command is used because it results in a carrier post separation maximum airspeed of less than the 312 KCAS limit. The mated trim program is used for that purpose also.

The third step is to calibrate the orbiter pitch rate command during the post separation flight phase in order to maintain an orbiter normal load factor greater than 0.5 g's during the orbiter pitchover maneuver to ALT interface.

The fourth step is to calibrate the time duration of the orbiter pitch rate command during the post separation flight phase in order to limit the orbiter flight path angle to 27 deg nose down and 18 deg nose down for the tailcone off and tailcone on orbiter configuration, respectively.

4.0 RESULTS

This section first presents the intermediate results of the analytical approach as outlined in Section 3.3. The separation reference trajectory results are then presented.

The orbiter/carrier separation initial flight conditions are tabulated in Table 1. Those results are a product of step one of the analytical approach.

The carrier and orbiter steering summary is tabulated in Table 2. Those results are a product of steps two through four of the analytical approach.

The results of the orbiter/carrier separation reference trajectory generation are presented in Tables 3 and 4 and Figures 1 through 26. Orbiter/carrier separation event schedule is tabulated in Table 3. Orbiter/carrier separation design specifications compatibility is summarized in Table 4. Time histories of parameters of interest are illustrated in Figures 1 through 26.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The orbiter/carrier separation reference trajectories documented herein satisfy all known separation design requirements. It is therefore recommended that the event sequence and steering summary reported herein be incorporated into the development of the ALT free flight #1 reference trajectories.

6.0 REFERENCES

1) JSC Memo No. FM42 (76-4), "A Description of the MPAD Working Relationship With FOD and Requested Deliverables," January 30, 1976.

2) RI Document SD74-SH-0271A, "Level C Functional Subsystem Software Requirements Document", dated November 1974.

3) NASA Memo No. EJ3-74-171, "Definition of 747 FCS and Orbiter FCS for Carrier/Orbiter Simulations at NASA", dated September 1974.

4) "Orbiter/747 Carrier Separation Aerodynamic Data Book", RI Document SD75-SH-0033-A, dated August 1975.

5) JSC Shuttle Operational Data Submittal WC-R-S219, "Aerodynamic Data", dated 29 January 1976 .

6) TBC Document No. D180-18401-6, "Boeing 747 Space Shuttle Orbiter Carrier Aircraft Modification (CAM) Mass Properties Status Report", dated September 1975.

TABLE 1 ORBITER/CARRIER SEPARATION INITIAL CONDITIONS

PARAMETER	TAILCONE OFF		TAILCONE ON	
	CARRIER	ORBITER	CARRIER	ORBITER
WEIGHT - LBS	354,028.00	150,000.00	344,088.00	150,000
INCIDENCE ANGLE - DEG		5.5		6.5
ELEVATOR(ON)- DEG	0.0	3.26	0.0	-0.35
RELATIVE LOAD FACTOR - g's		0.748		0.748
PITCH ACCELERATION - DEG/SEC^2		4.0		4.0
ALTITUDE - FT AGL	17,109.00	17,135.00	22,159.00	22,186.00
AIRSPEED - KEAS	273.00	273.00	262.00	262.00
TRUE AIRSPEED - FT/SEC	624.00	624.00	653.00	653.00
FLIGHT PATH ANGLE - DEG	-11.63	-11.63	-9.1	-9.1
ANGLE OF ATTACK - DEG	2.63	8.13	2.72	9.22
HORIZONTAL TAIL POSITION - DEG	2.62		3.56	
PITCH ATTITUDE - DEG	-9.0	-3.5	-6.38	0.12
PITCH ATTITUDE COMMAND - DEG	-9.0		-6.38	
PITCH ATTITUDE RATE COMMAND - DEG/SEC		2.0		2.0
THRUST - LB	2,515.00		1,352.00	

TABLE 2 ORBITER/CARRIER SEPARATION STEERING SUMMARY

(TIME IS REFERENCED TO PHYSICAL SEPARATION)

TAILCONE CONFIGURATION	OFF	ON
SEPARATION AIRSPEED (KEAS)	273.00	262.00
CARRIER PITCH ATTITUDE COMMAND FOR MATED EQ. GLIDE (DEG)	-9.0	-6.38
CARRIER PITCH ATTITUDE COMMAND FOR POST-SEPARATION CARRIER EQ. GLIDE (DEG)	-5.0	-4.38
START TIME OF CARRIER POST-SEPARATION EQ. GLIDE PITCH COMMAND (SEC)	4.0	4.0
START TIME OF CARRIER 30 DEG. ROLL COMMAND AT 10 DEG/SEC (SEC).	2.0	2.0
ORBITER PITCH RATE COMMAND DURING SEPARATION FIRST 3 SEC/LAST 2 SEC (DEG/SEC)	2.0/0.0	2.0/0.0
ORBITER PITCH RATE COMMAND DURING POST SEPARATION (DEG/SEC)	-1.4	-1.35
STOP TIME OF ORBITER POST SEPARATION PITCH RATE COMMAND (SEC)	22.2	19.0

TABLE 3 ORBITER/CARRIER SEPARATION EVENT SCHEDULE

EVENT	TIME (SEC) TAILCONE OFF	TIME (SEC) TAILCONE ON
SEPARATE AND INITIATE ORBITER PULLUP MANEUVER	0.0	0.0
INITIATE CARRIER ROLL MANEUVER	2.0	2.0
INITIATE ORBITER ATTITUDE HOLD	3.0	3.0
SEPARATION CLEARANCE ATTAINED	3.2	3.2
INITIATE CARRIER PULLUP MANEUVER	4.0	4.0
INITIATE ORBITER PUSHOVER MANEUVER	5.0	5.0
ALT INTERFACE FLIGHT PATH ANGLE ATTAINED	25.8	21.8
	(γ = -27°)	(γ = -18°)

TABLE 4 ORBITER/CARRIER SEPARATION DESIGN COMPATIBILITY SUMMARY

ORBITER TAILCONE CONFIGURATION	OFF	ON
SEPARATION AIRSPEED (KEAS)	273.00	262.00
RELATIVE NORMAL LOAD FACTOR AT SEPARATION ≥.75 g's	.748	.748
ORBITER PITCH ACCELERATION AT SEPARATION ≈4 DEG/SEC	4.0	4.0
VERTICAL CLEARANCE AT TSEP + 4 SEC ≥ 140 FT	160.00	174.00
CARRIER LOAD FACTOR RANGE ≥ .5 g's & ≤ 2.0 g's	.77-1.58	.77-1.39
ORBITER LOAD FACTOR RANGE ≥ .5 g's & ≤ 2.0 g's	.52-1.78	.52-1.7
MAXIMUM CARRIER AIRSPEED ≤ 312 KCAS	286.00	273.00

FIGURE 1
ALT FREE FLIGHT #1 REFERENCE TRAJECTORY
TAILCONE ON
SEPARATION CLEARANCE

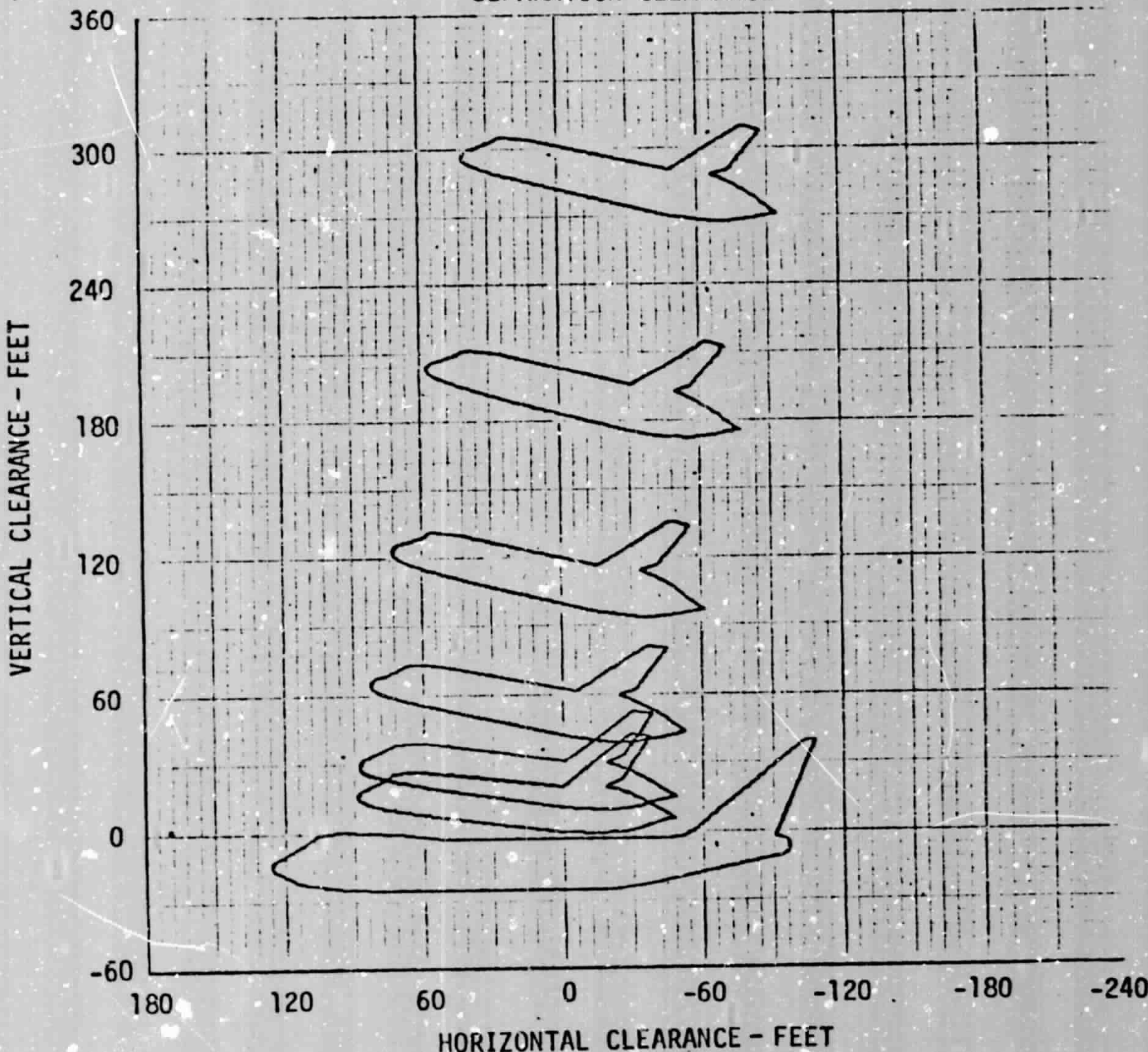

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FIGURE 2
ALT FREE FLIGHT #1 REFERENCE TRAJECTORY
TAILCONE ON
MINIMUM PATH DISTANCE TIME HISTORY

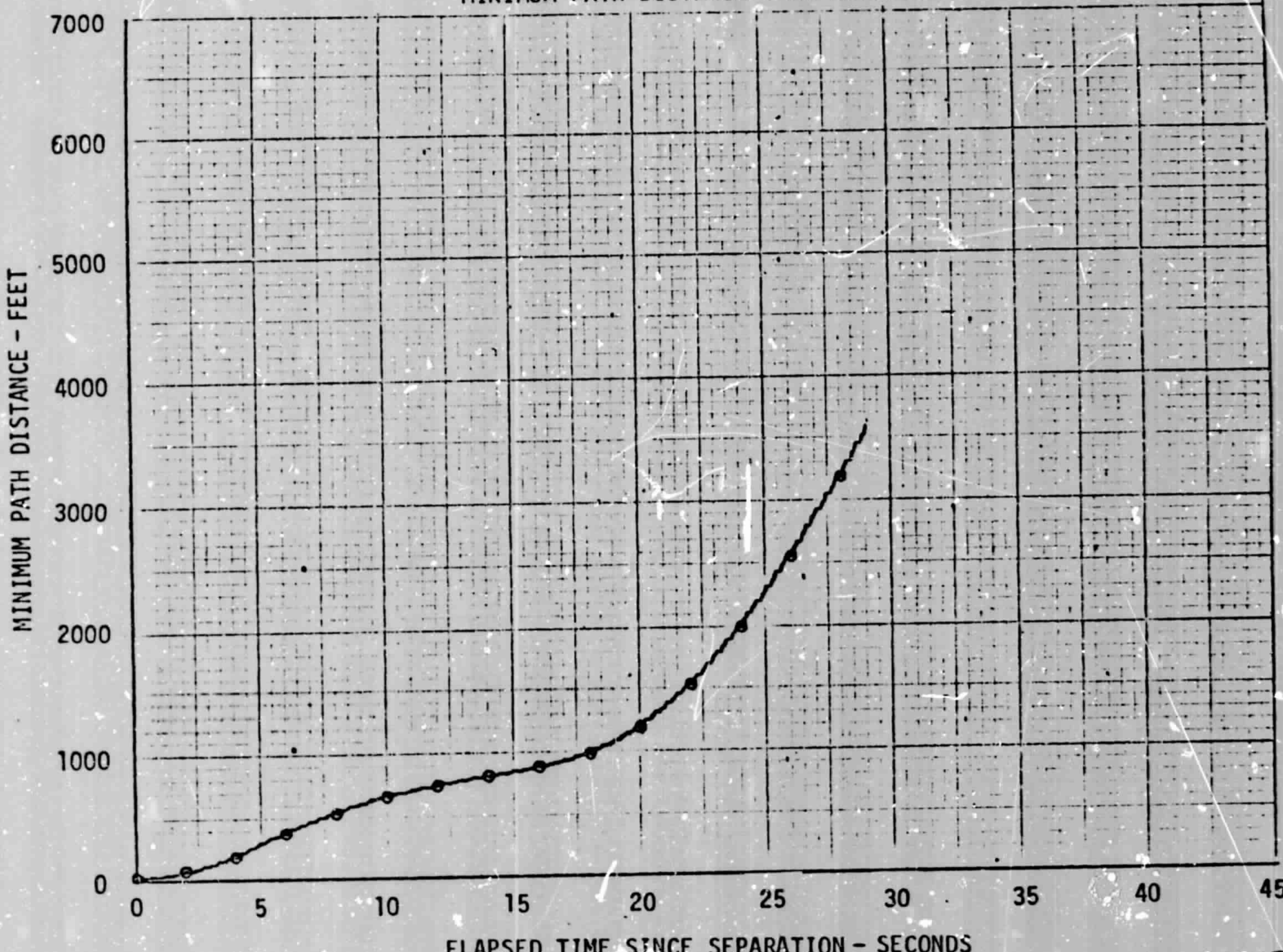

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FIGURE 3

ALT FREE FLIGHT #1 REFERENCE TRAJECTORY

TAILCONE ON

RELATIVE VERTICAL RANGE VERSUS RELATIVE DOWN RANGE

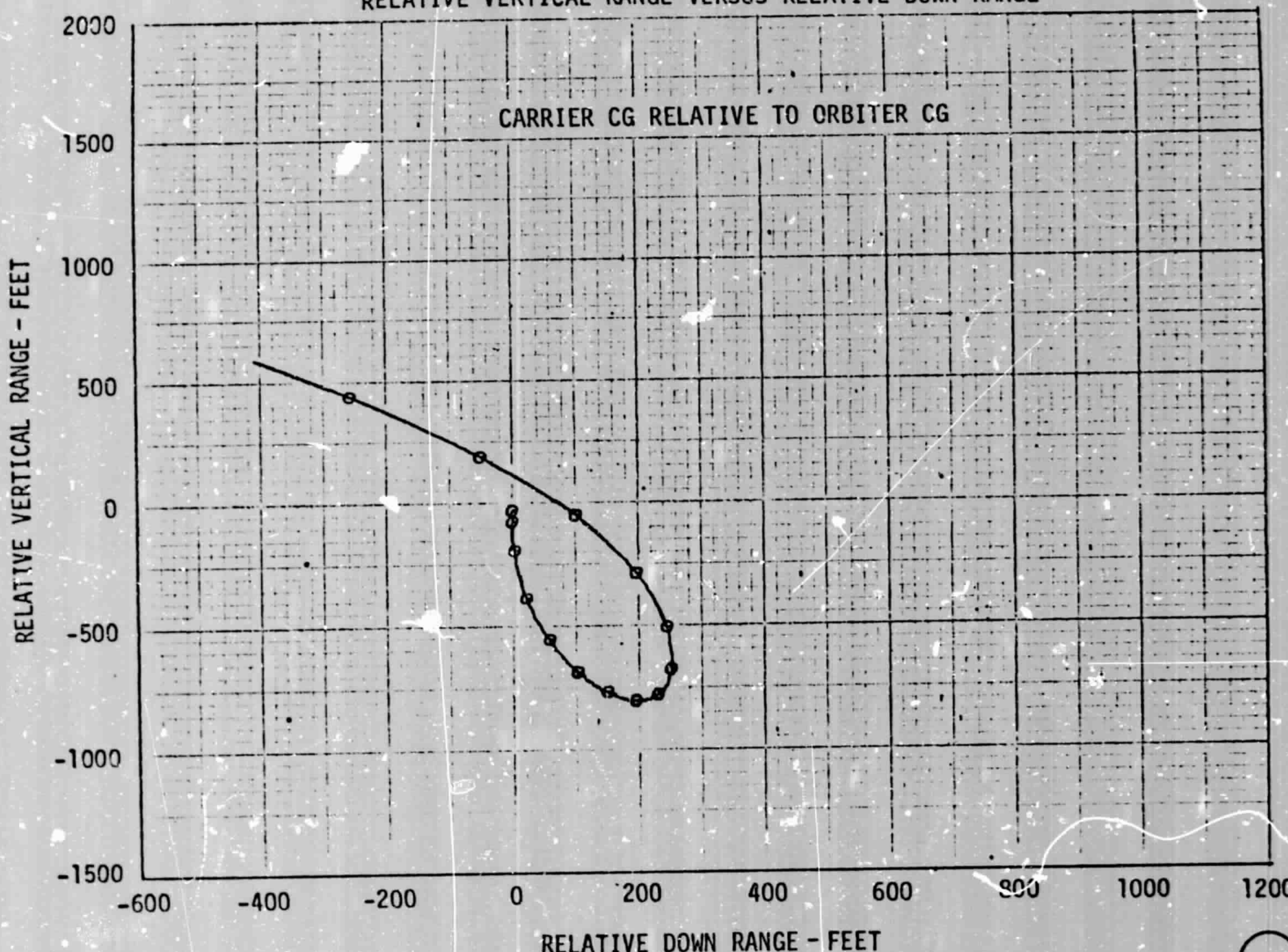

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FIGURE 4
ALT FREE FLIGHT #1 REFERENCE TRAJECTORY
TAILCONE ON
RELATIVE CROSS RANGE VERSUS RELATIVE DOWN RANGE

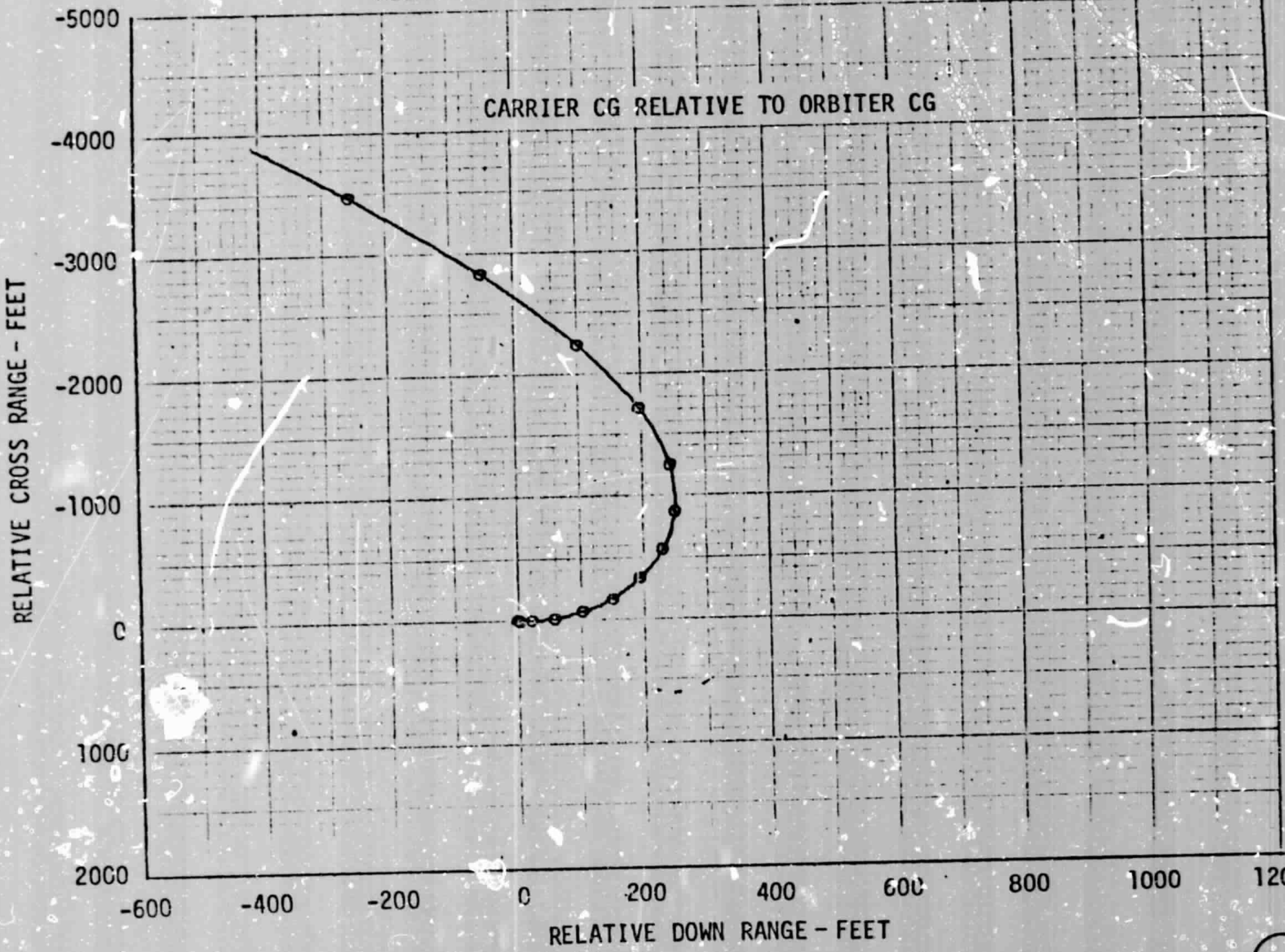

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FIGURE 5
ALT FREE FLIGHT #1 REFERENCE TRAJECTORY
TAILCONE ON
RELATIVE VERTICAL RANGE VERSUS RELATIVE CROSS RANGE

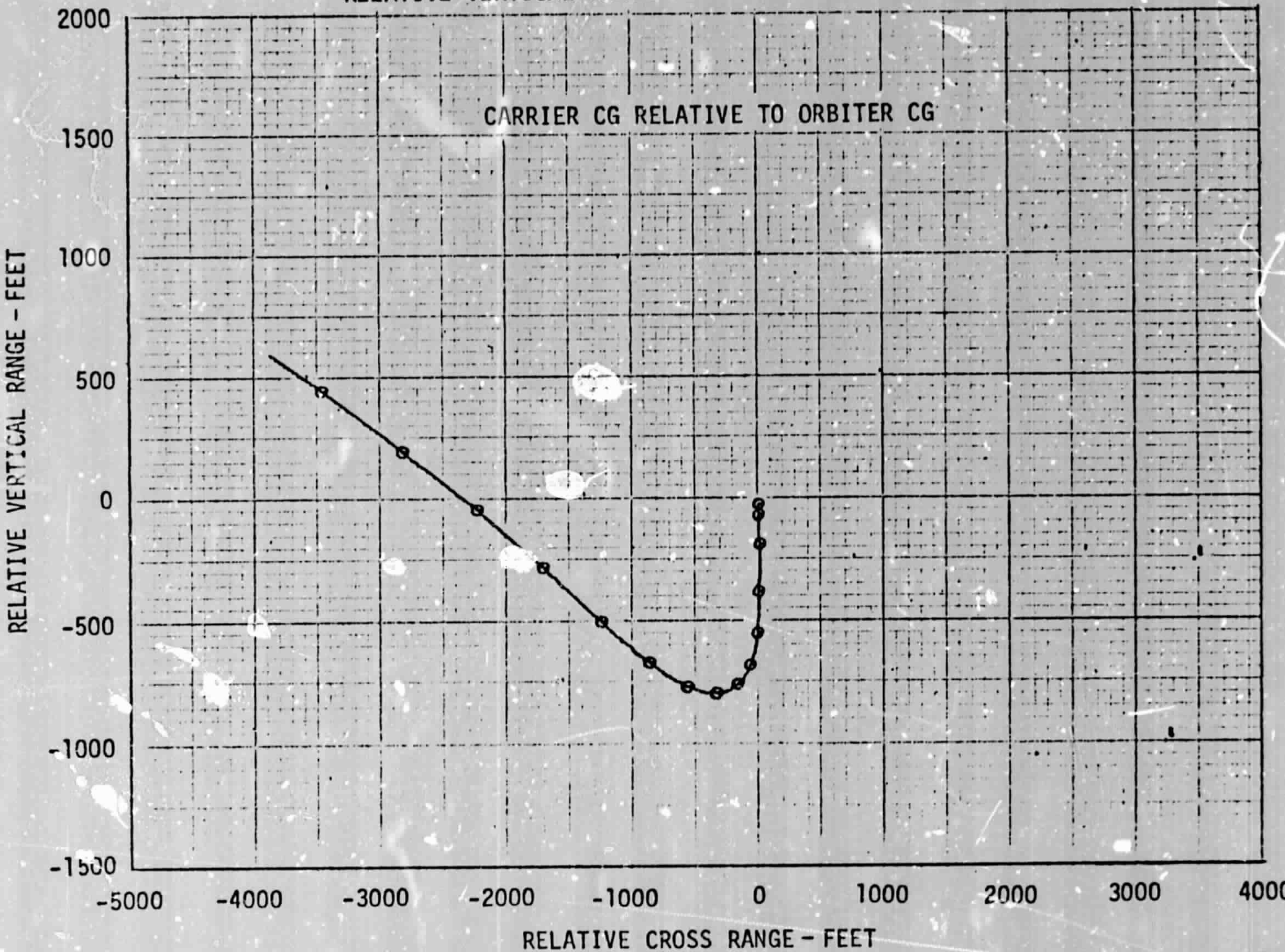

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FIGURE 6

ALT FREE FLIGHT #1 REFERENCE TRAJECTORY

TAILCONE ON

ALTITUDE TIME HISTORY

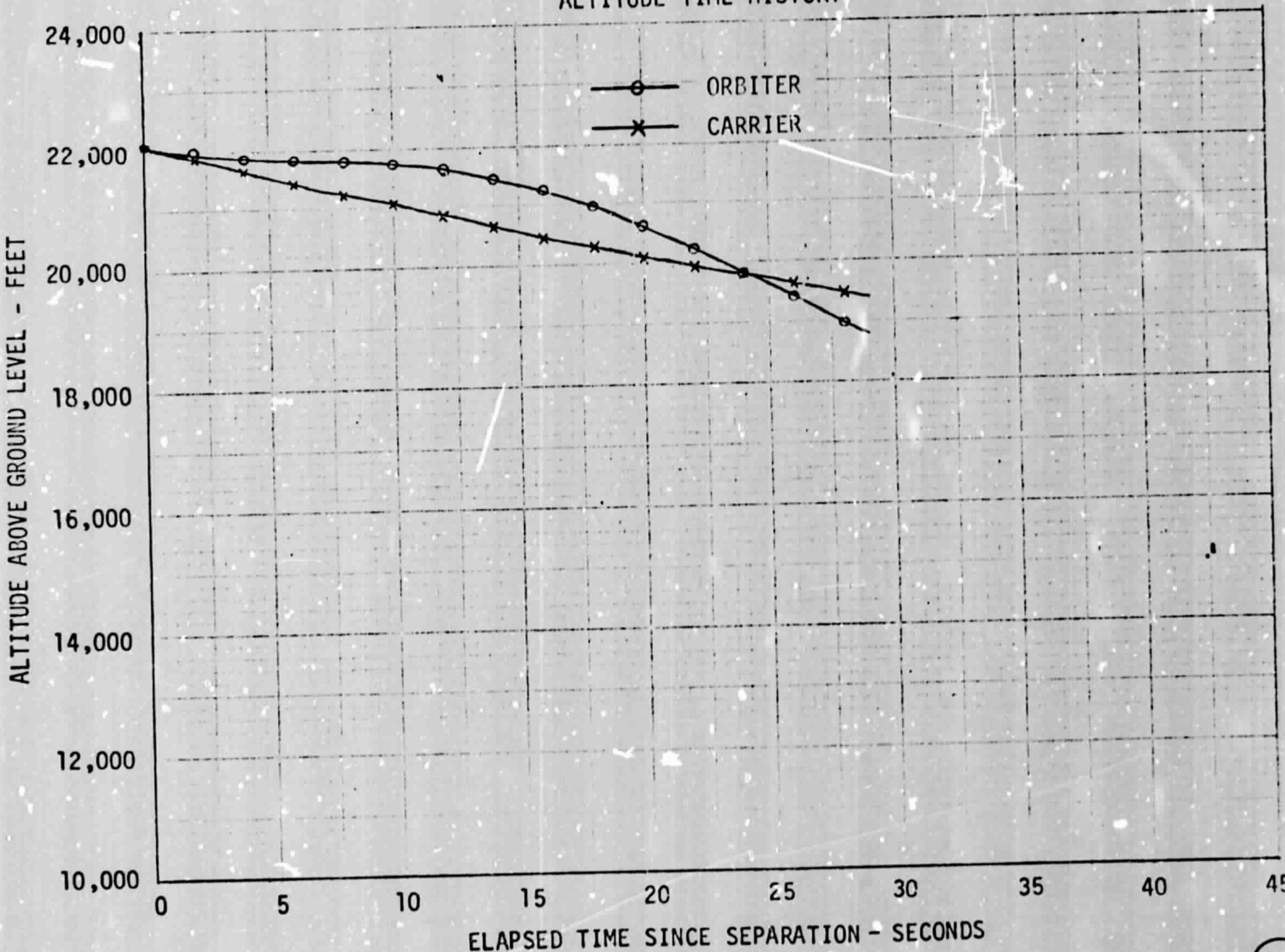

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FIGURE 7

ALT FREE FLIGHT #1 REFERENCE TRAJECTORY

TAILCONE ON

AIRSPEED TIME HISTORY

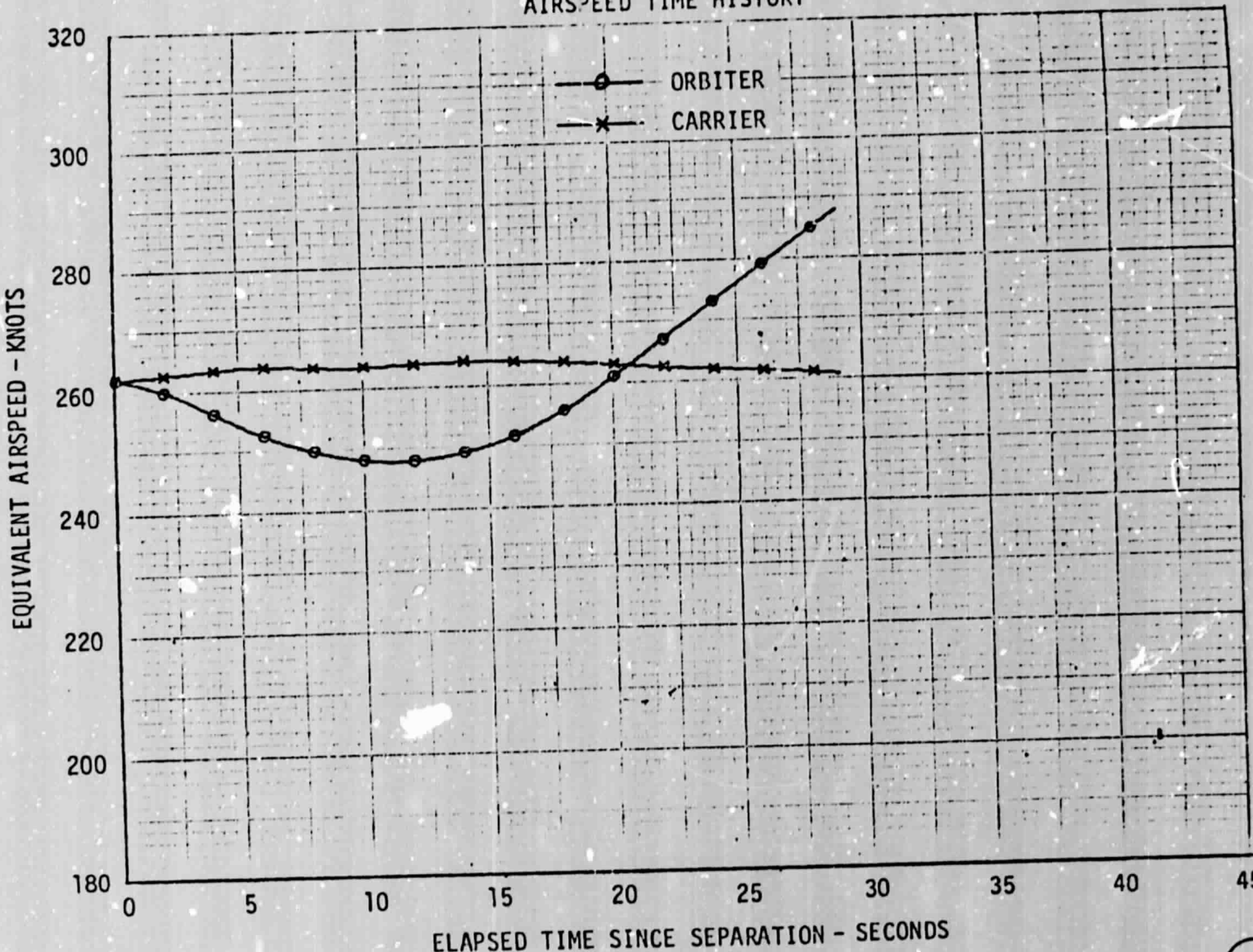

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FIGURE 8

ALT FREE FLIGHT #1 REFERENCE TRAJECTORY

TAILCONE ON

FLIGHT PATH ANGLE TIME HISTORY

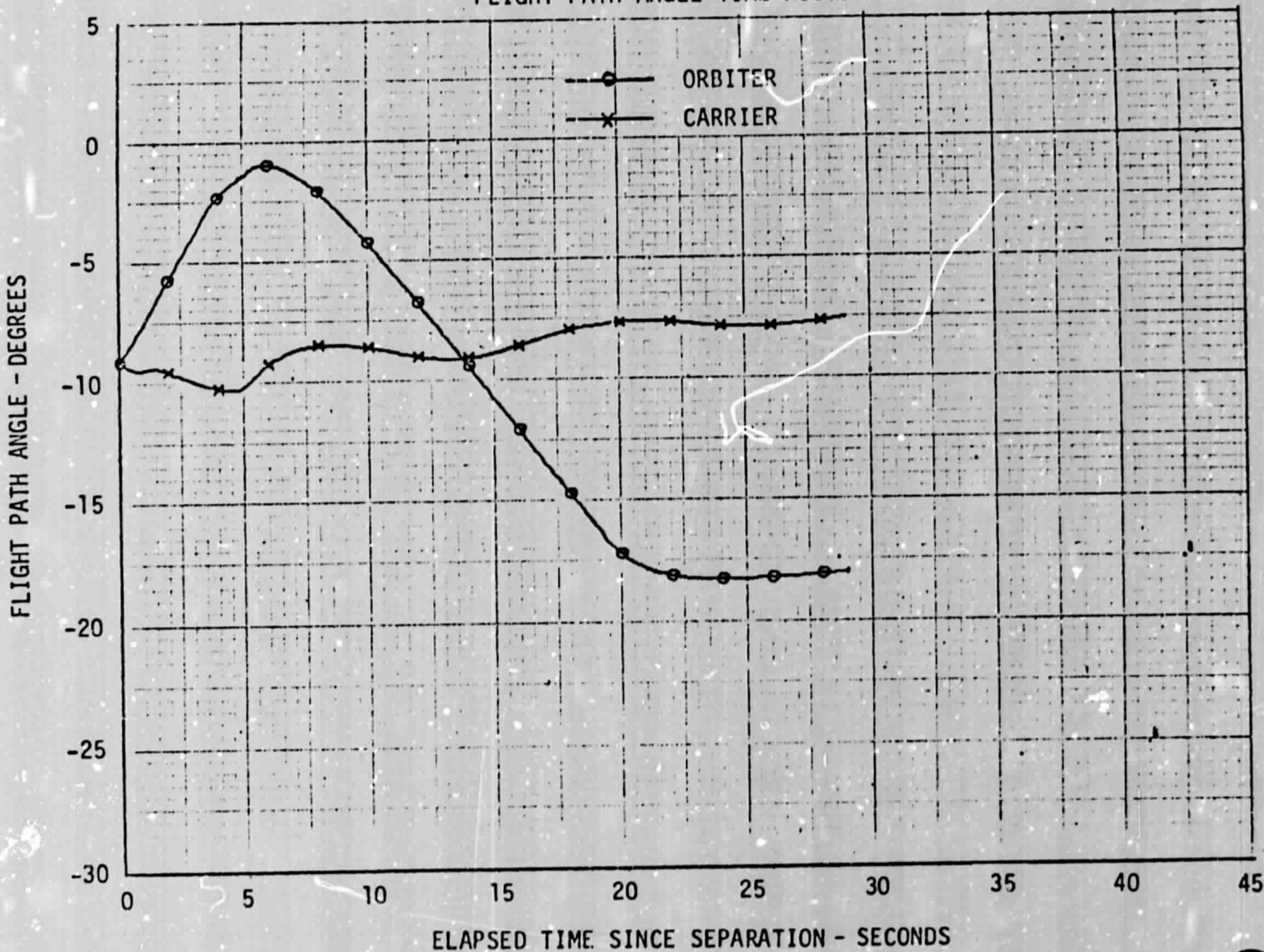

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FIGURE 9
ALT FREE FLIGHT #1 REFERENCE TRAJECTORY
TAILCONE ON
RELATIVE NORMAL LOAD FACTOR TIME HISTORY

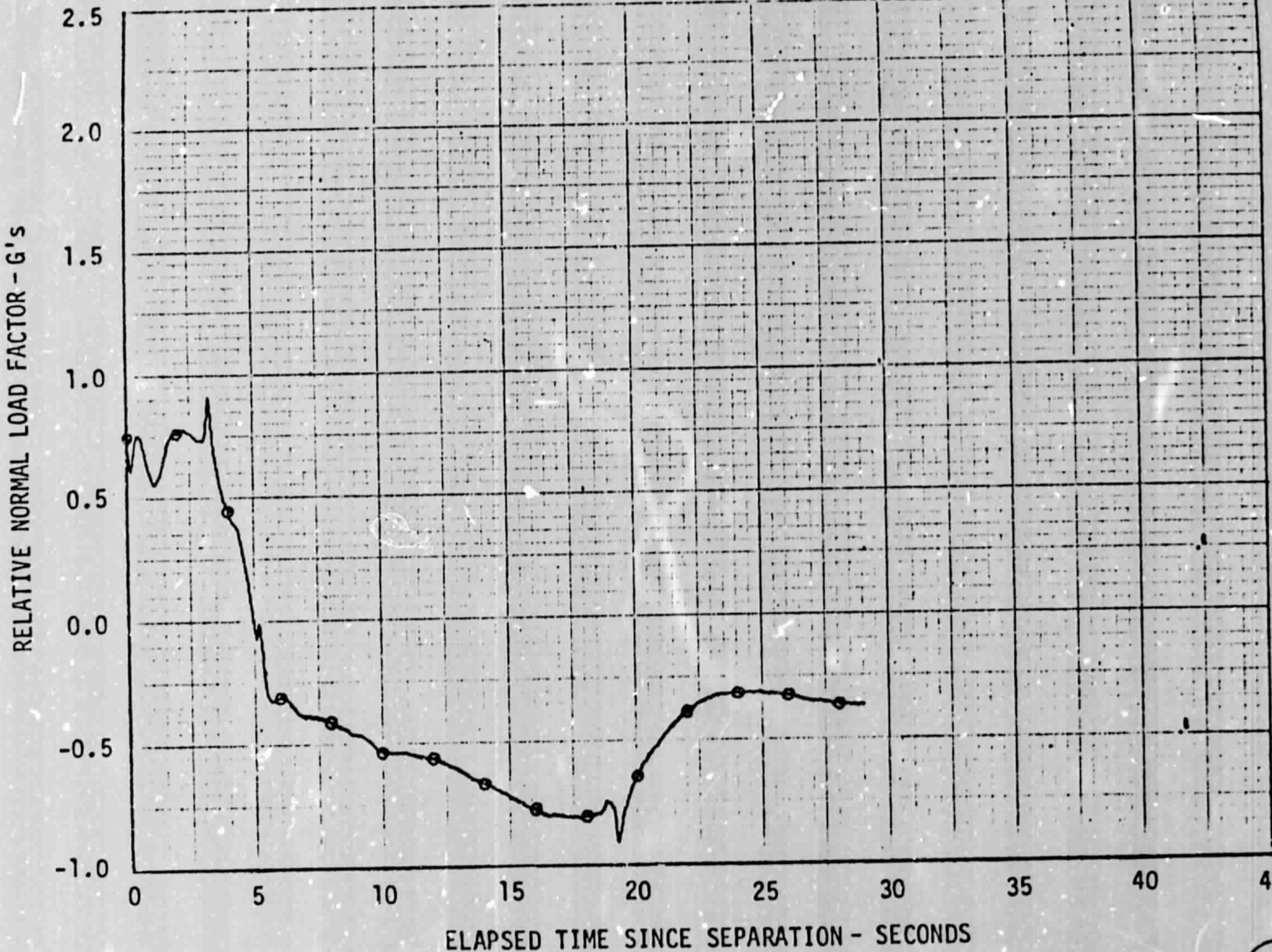

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FIGURE 10
ALT FREE FLIGHT #1 REFERENCE TRAJECTORY
TAILCONE ON

NORMAL LOAD FACTOR TIME HISTORY

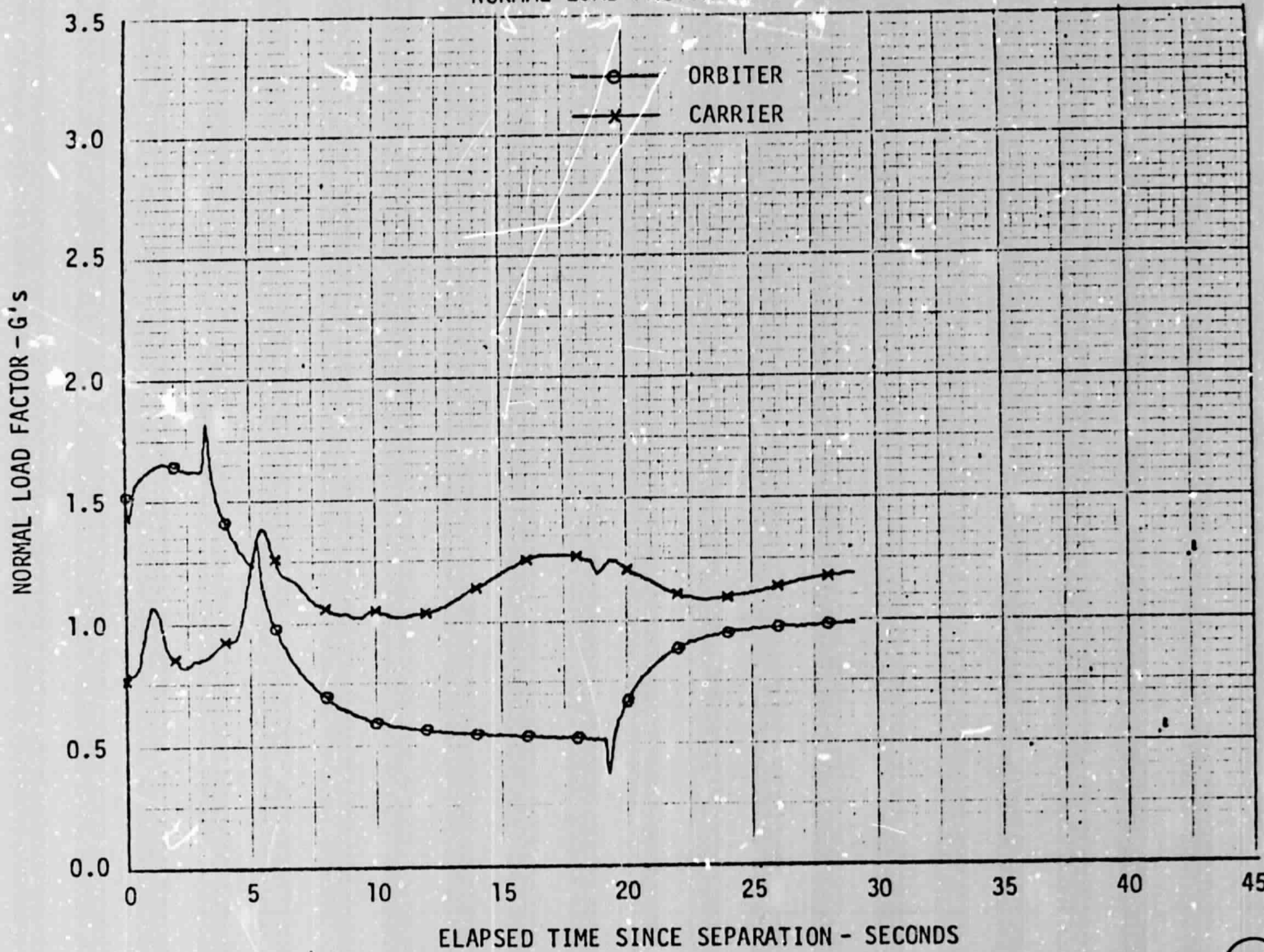

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FIGURE 11
ALT FREE FLIGHT #1 REFERENCE TRAJECTORY
TAILCONE ON

ORBITER PITCH RATE COMMAND AND RESPONSE TIME HISTORIES

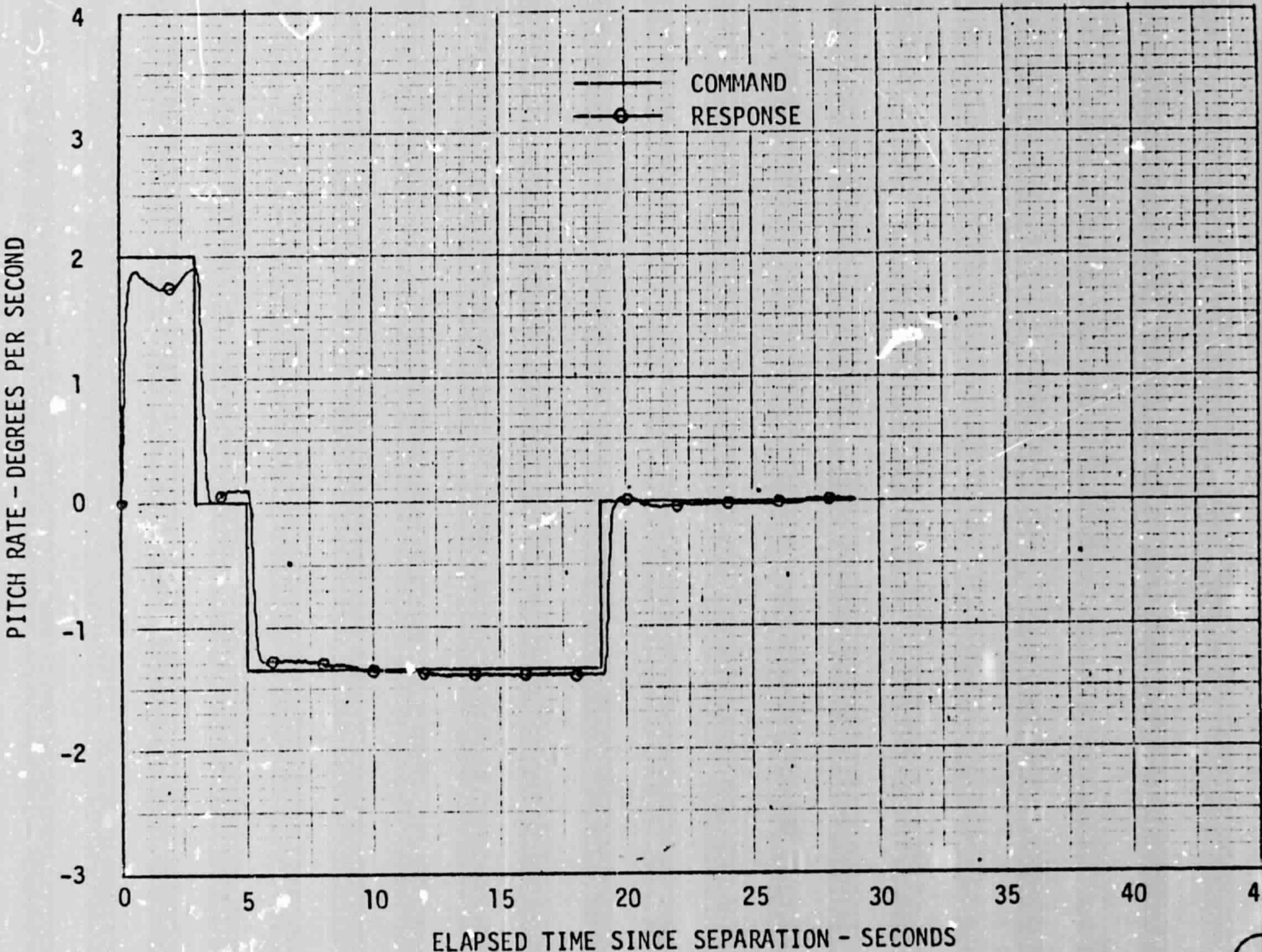

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FIGURE 12
ALT FREE FLIGHT #1 REFERENCE TRAJECTORY
TAILCONE ON

ANGLE OF ATTACK TIME HISTORY

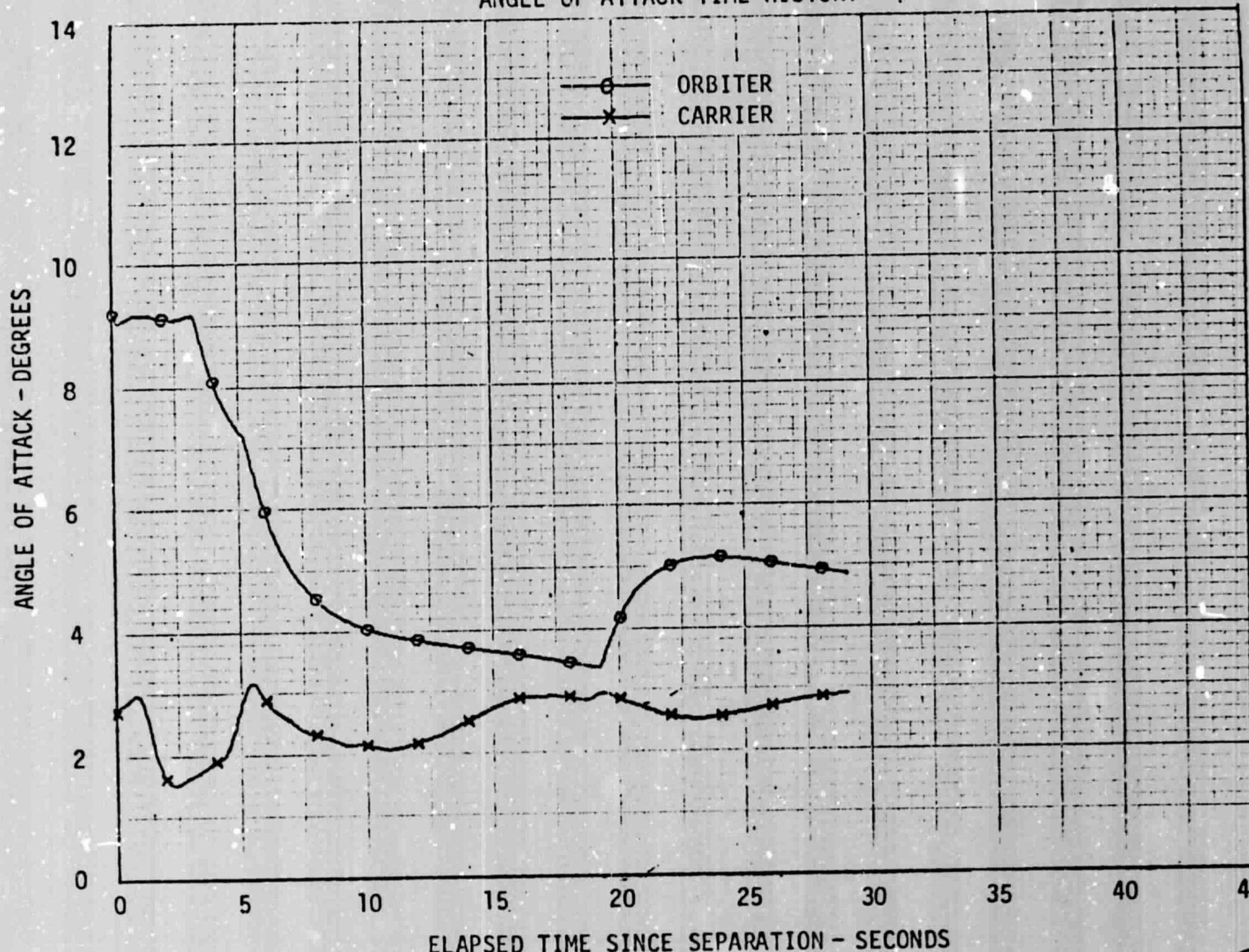

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FIGURE 13

ALT FREE FLIGHT #1 REFERENCE TRAJECTORY

TAILCONE ON

CARRIER ROLL ATTITUDE COMMAND AND RESPONSE TIME HISTORIES

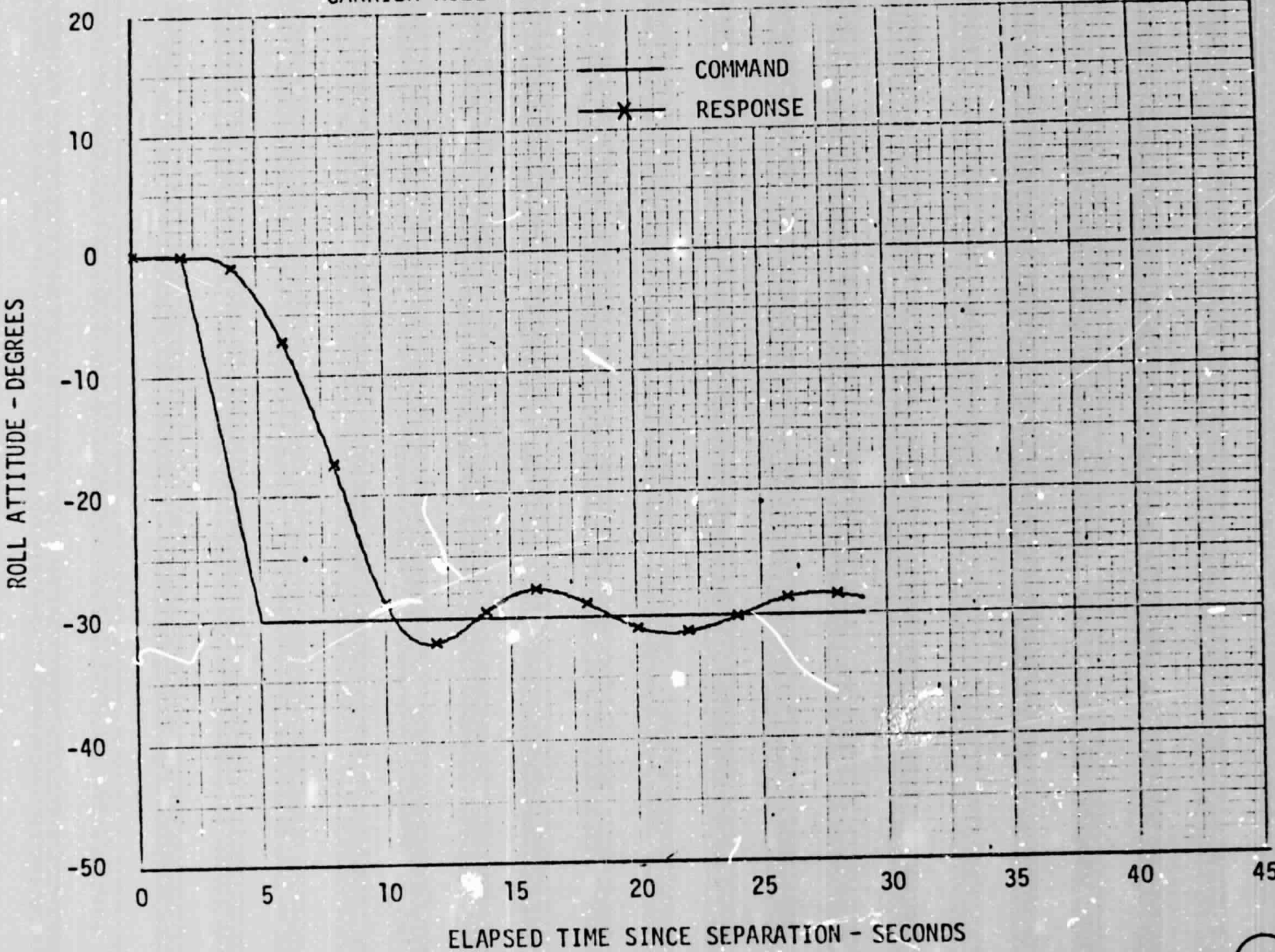

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FIGURE 14

ALT FREE FLIGHT #1 REFERENCE TRAJECTORY

TAILCONE OFF

SEPARATION CLEARANCE

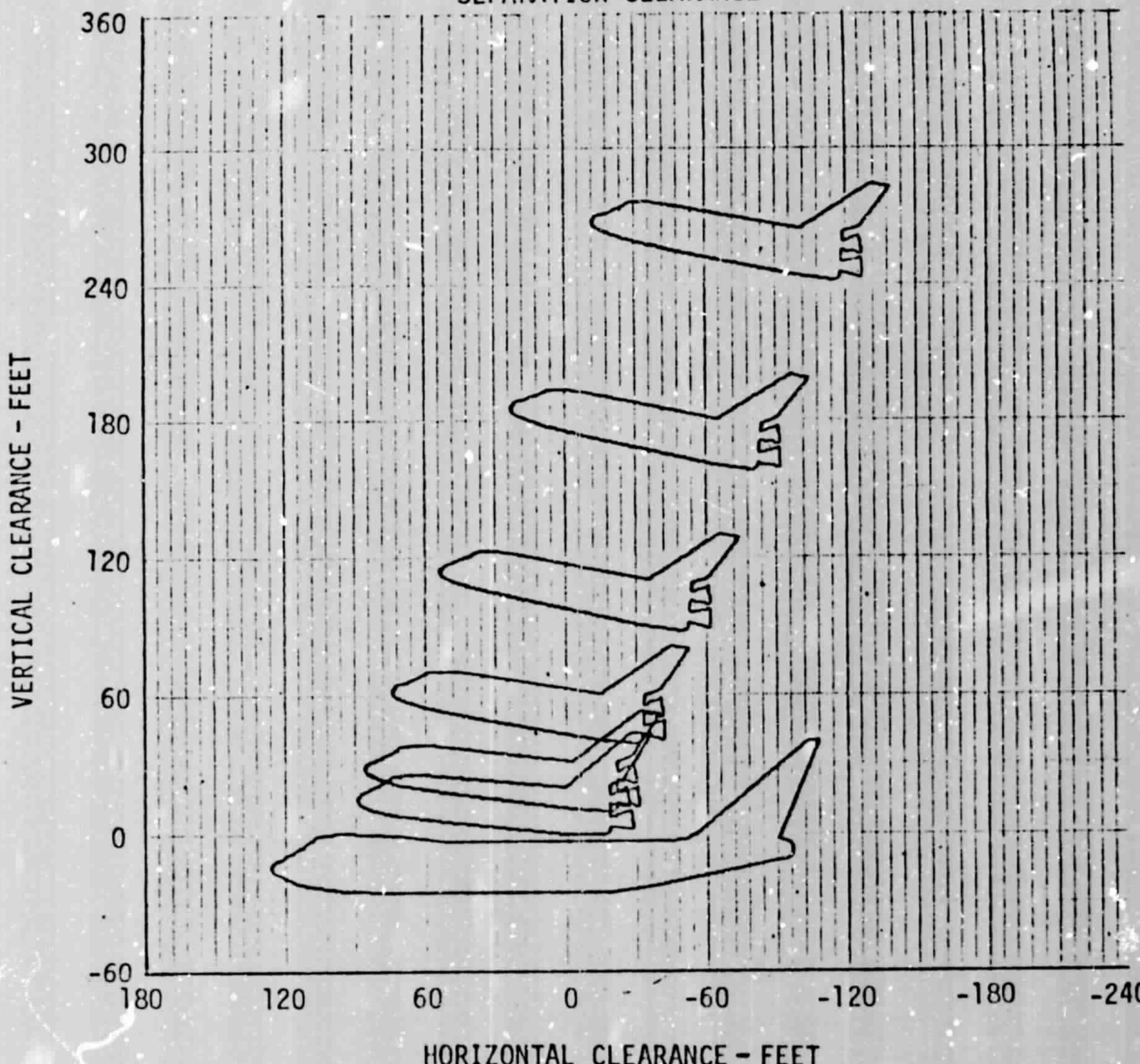

FIGURE 15

ALT FREE FLIGHT #1 REFERENCE TRAJECTORY

TAILCONE OFF

MINIMUM PATH DISTANCE TIME HISTORY

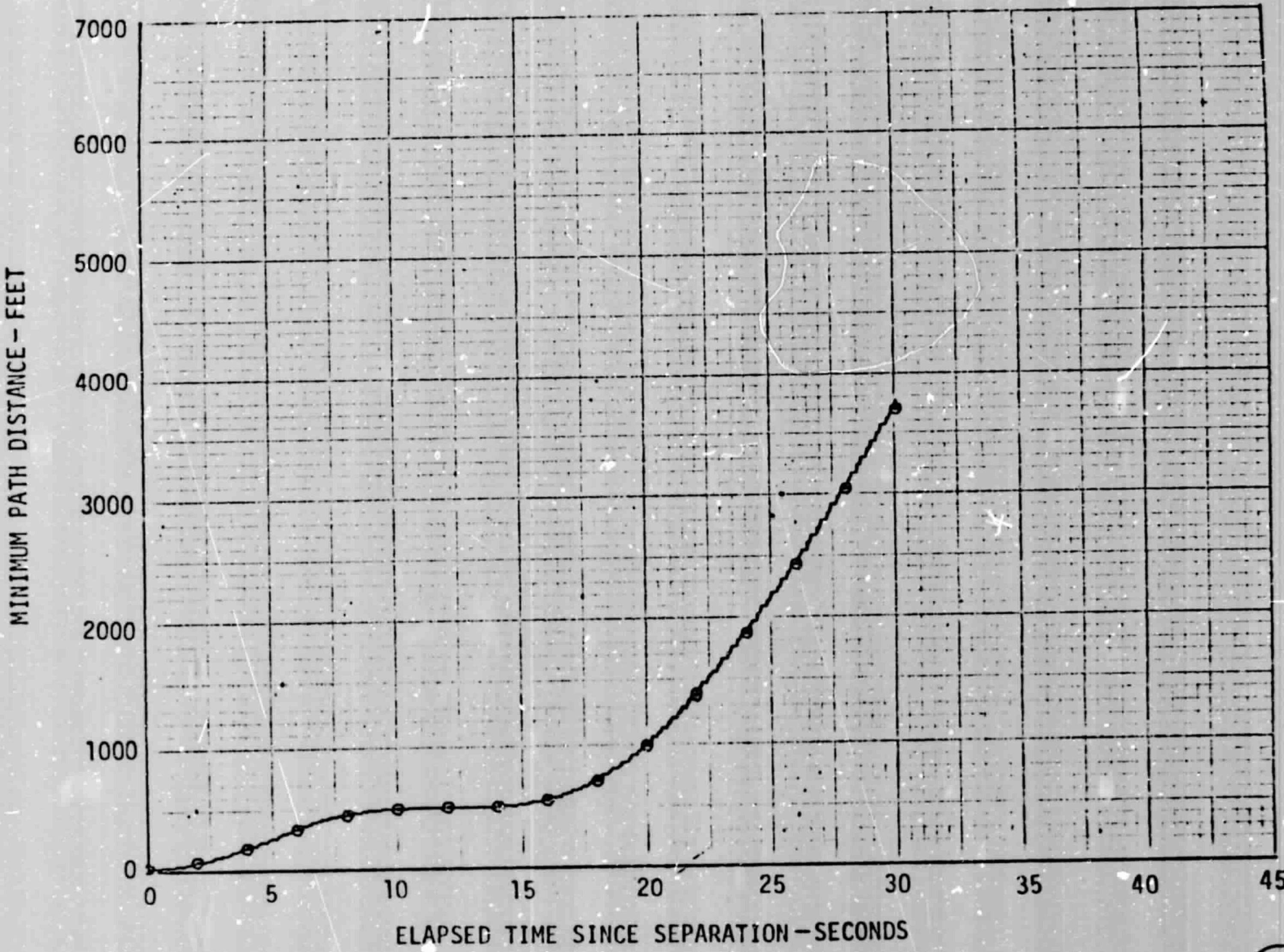

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FIGURE 16
ALT FREE FLIGHT #1 REFERENCE TRAJECTORY
TAILCONE OFF
RELATIVE VERTICAL RANGE VERSUS RELATIVE DOWN RANGE

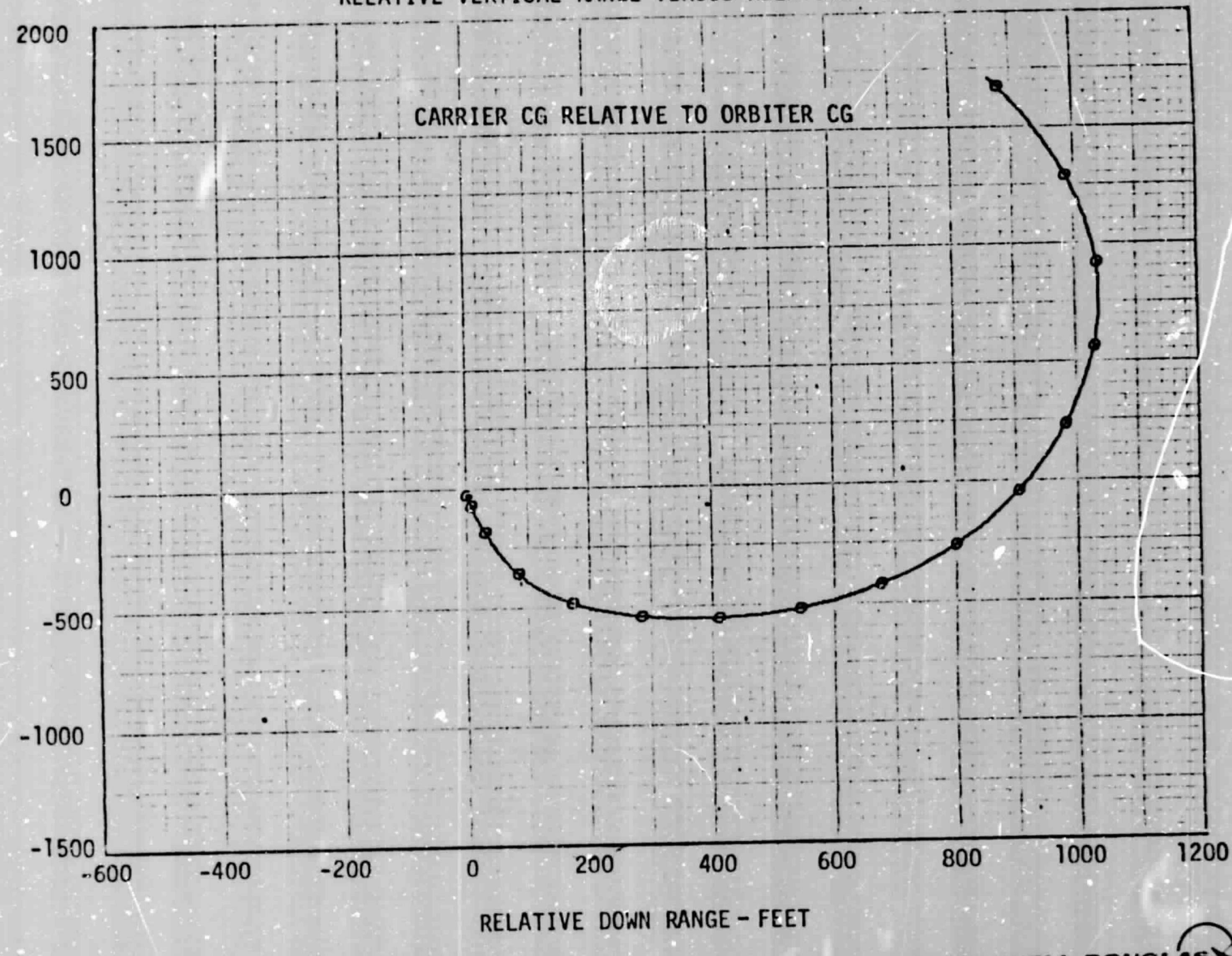

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FIGURE 17
ALT FREE FLIGHT #1 REFERENCE TRAJECTORY
TAILCONE OFF
RELATIVE CROSS RANGE VERSUS RELATIVE DOWN RANGE

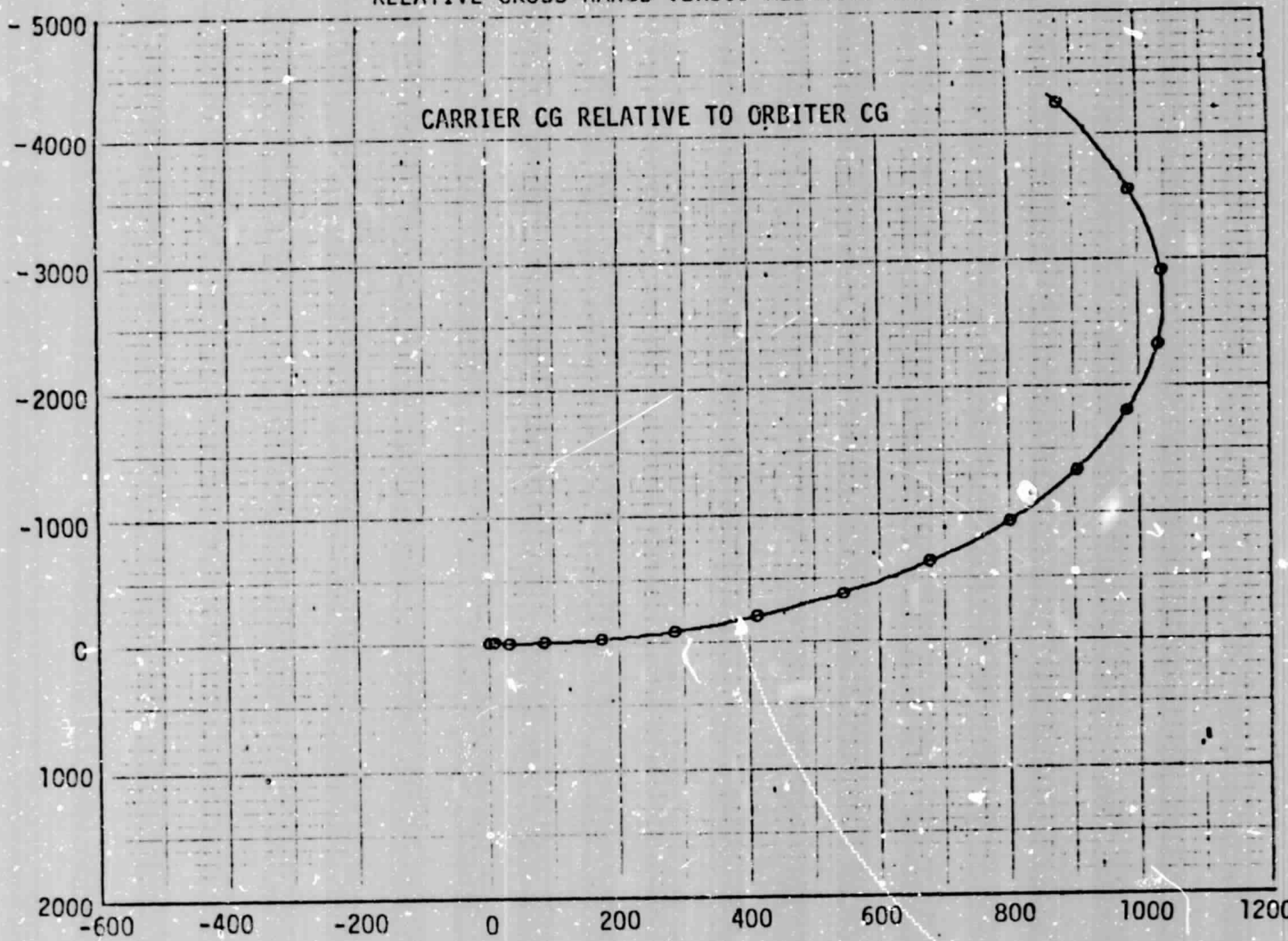

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FIGURE 18
ALT FREE FLIGHT #1 REFERENCE TRAJECTORY
TAILCONE OFF
RELATIVE VERTICAL RANGE VERSUS RELATIVE CROSS RANGE

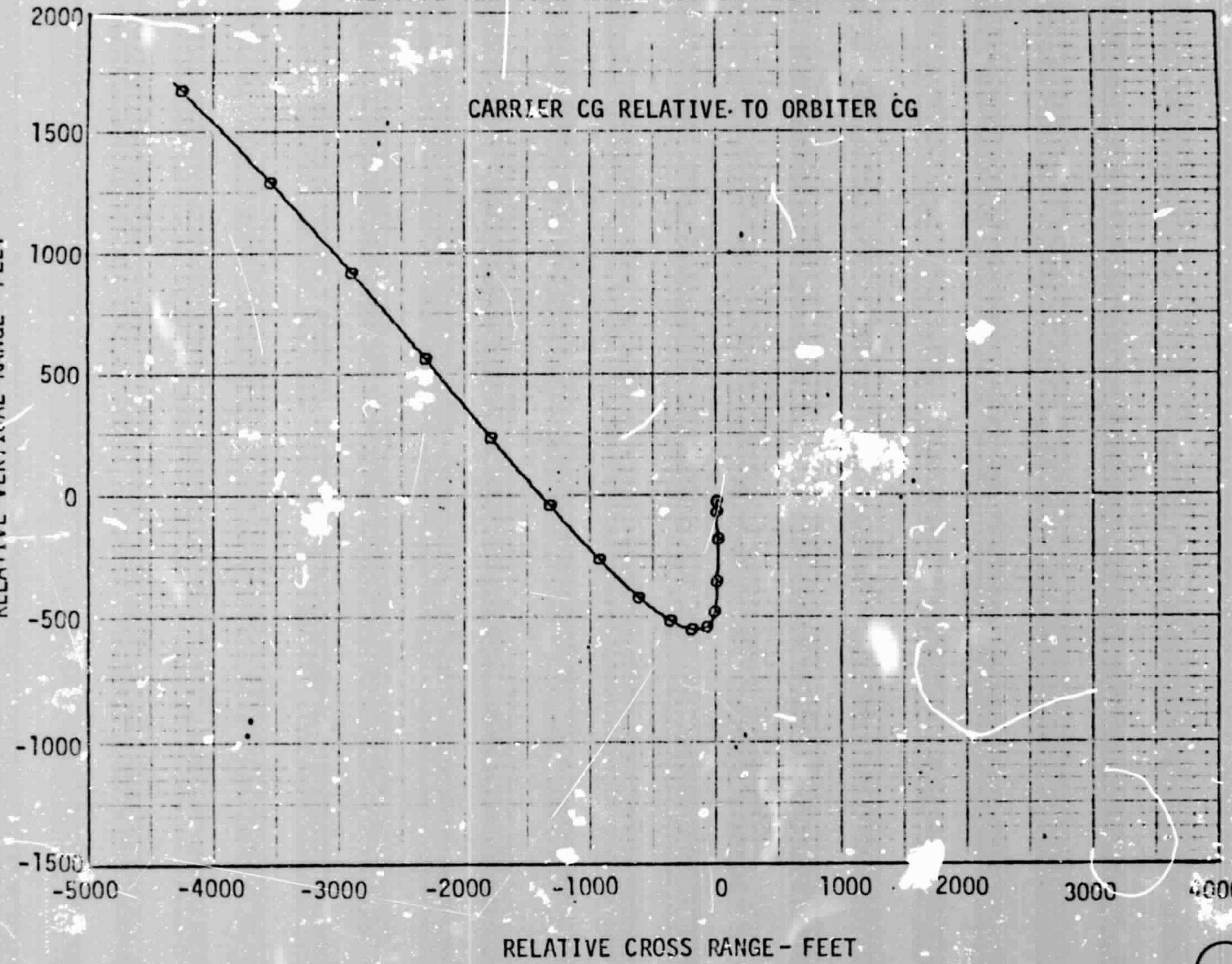

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FIGURE 19
ALT FREE FLIGHT #1 REFERENCE TRAJECTORY
TAILCONE OFF
ALTITUDE TIME HISTORY

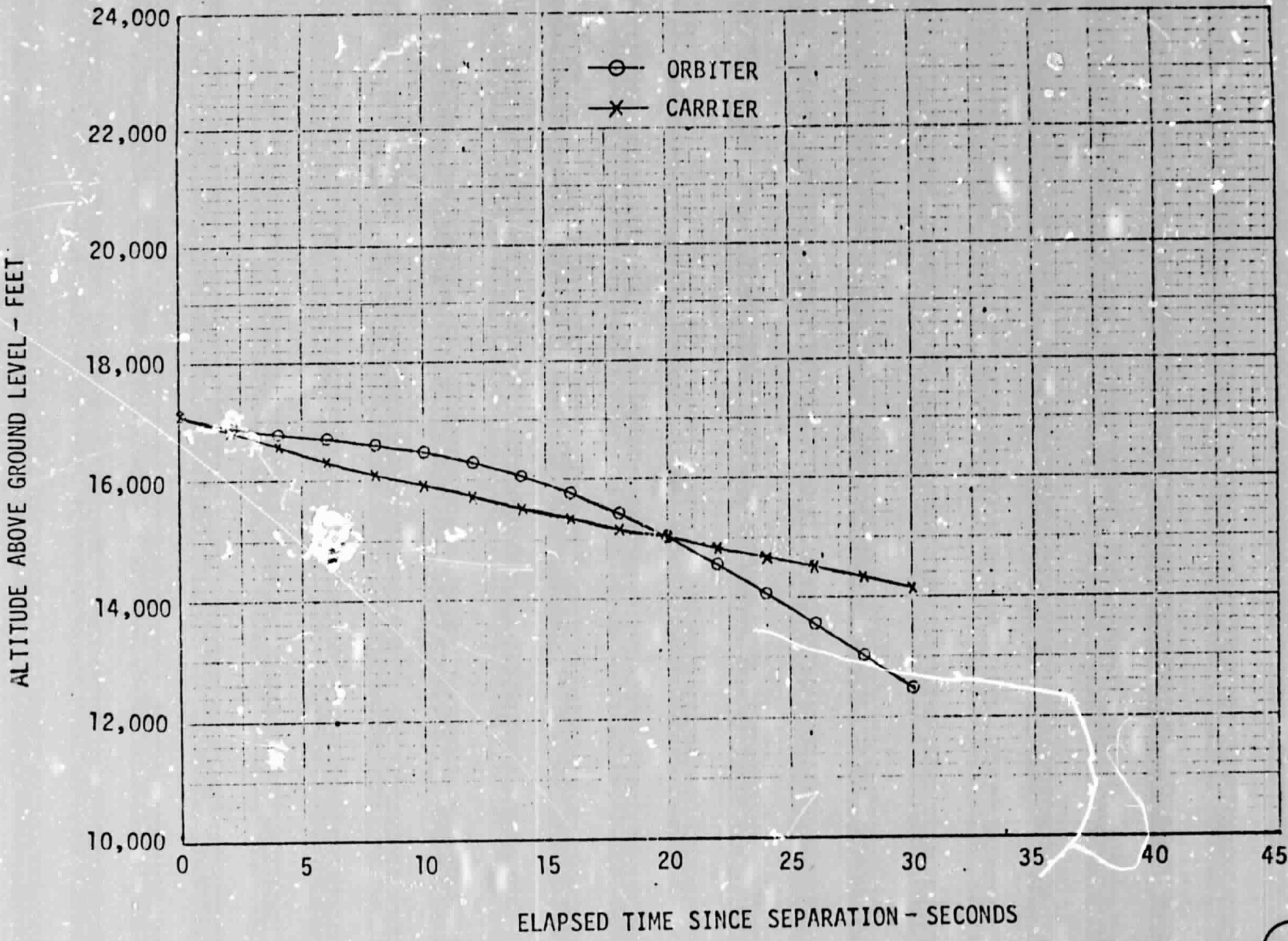

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FIGURE 20

ALT FREE FLIGHT #1 REFERENCE TRAJECTORY

TAILCONE OFF

AIRSPEED TIME HISTORY

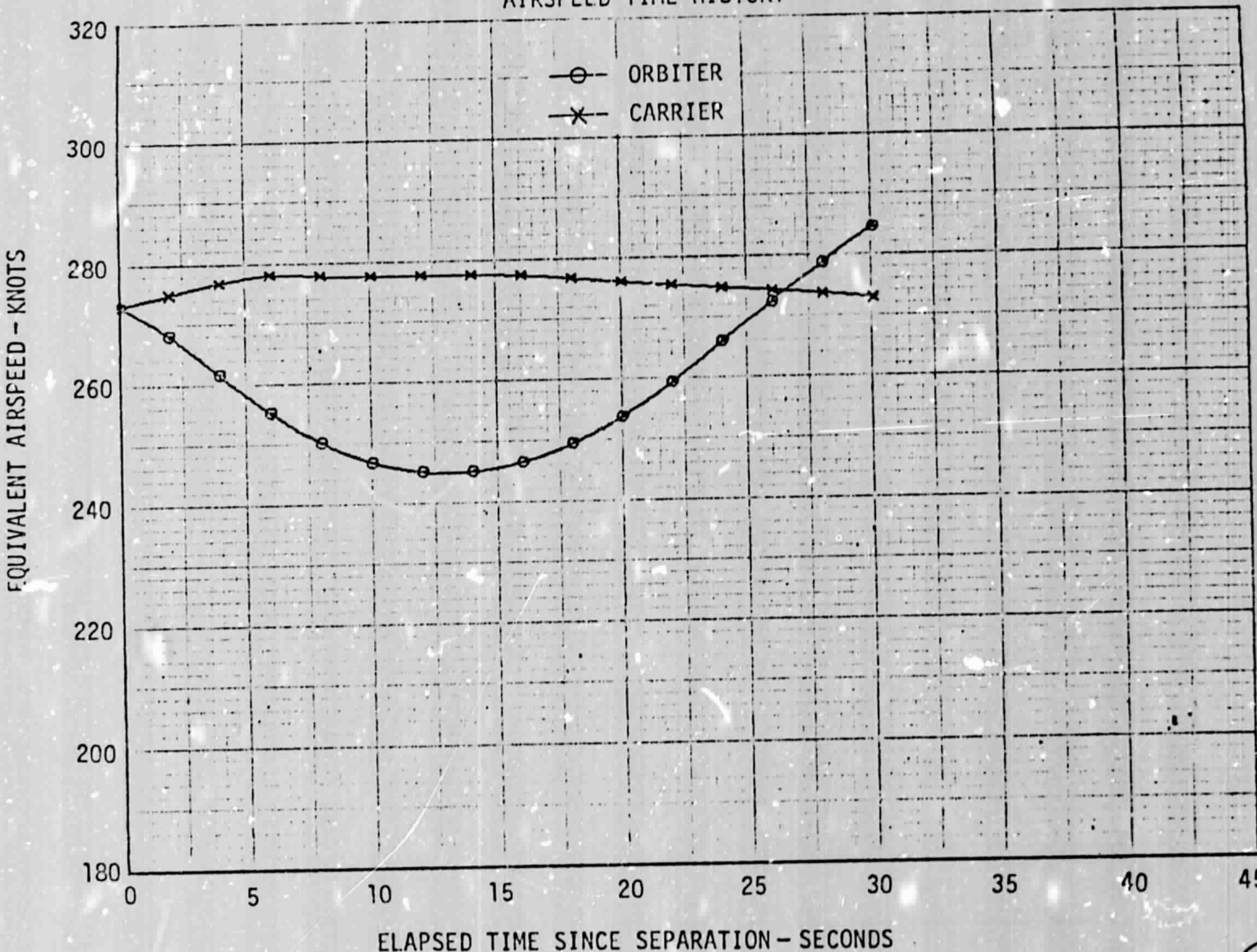

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FIGURE 21

ALT FREE FLIGHT #1 REFERENCE TRAJECTORY

TAILCONE OFF

FLIGHT PATH ANGLE TIME HISTORY

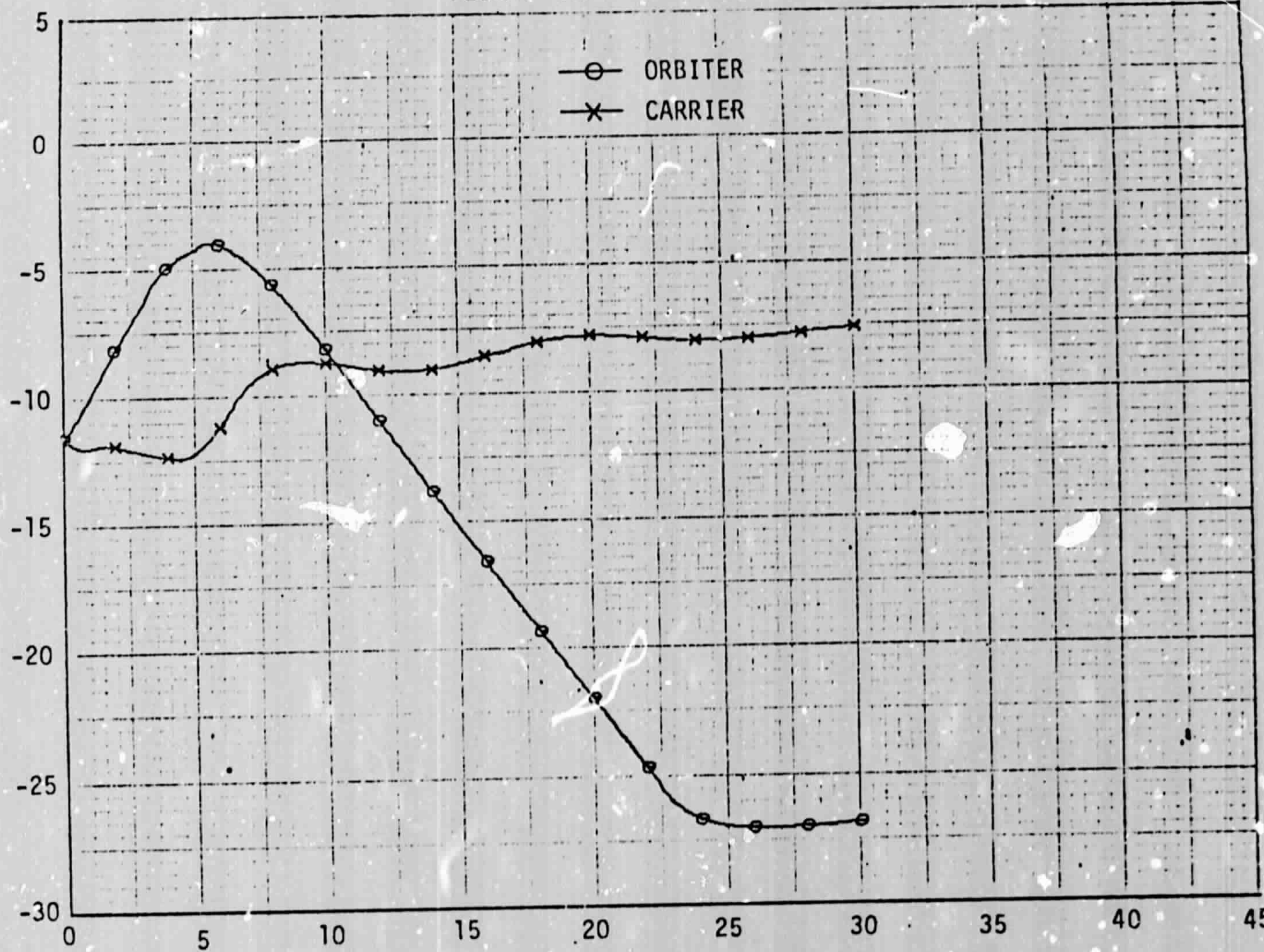

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FIGURE 22
ALT FREE FLIGHT #1 REFERENCE TRAJECTORY
TAILCONE OFF
RELATIVE NORMAL LOAD FACTOR TIME HISTORY

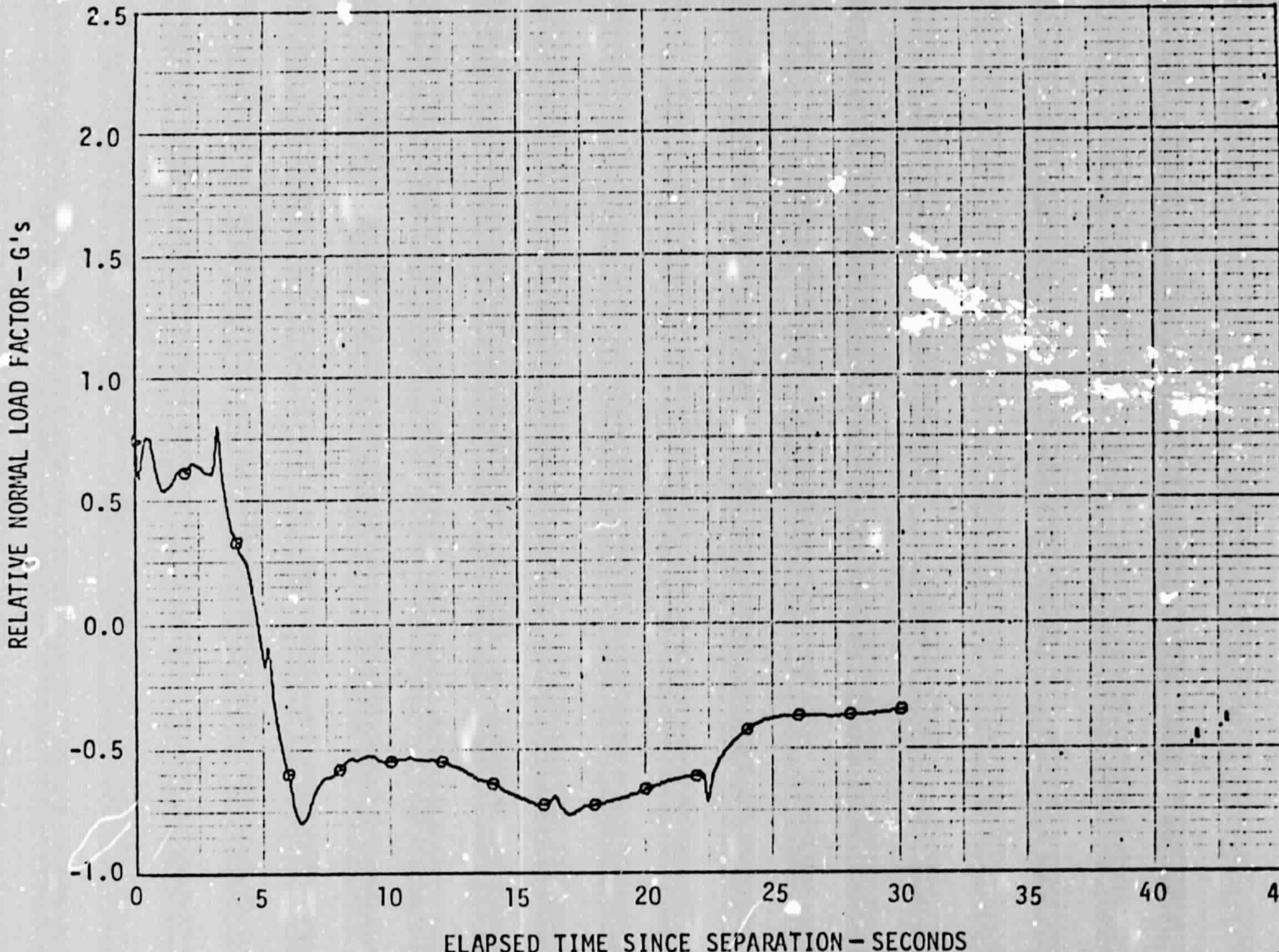

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FIGURE 23
ALT FREE FLIGHT #1 REFERENCE TRAJECTORY
TAILCONE OFF
NORMAL LOAD FACTOR TIME HISTORY

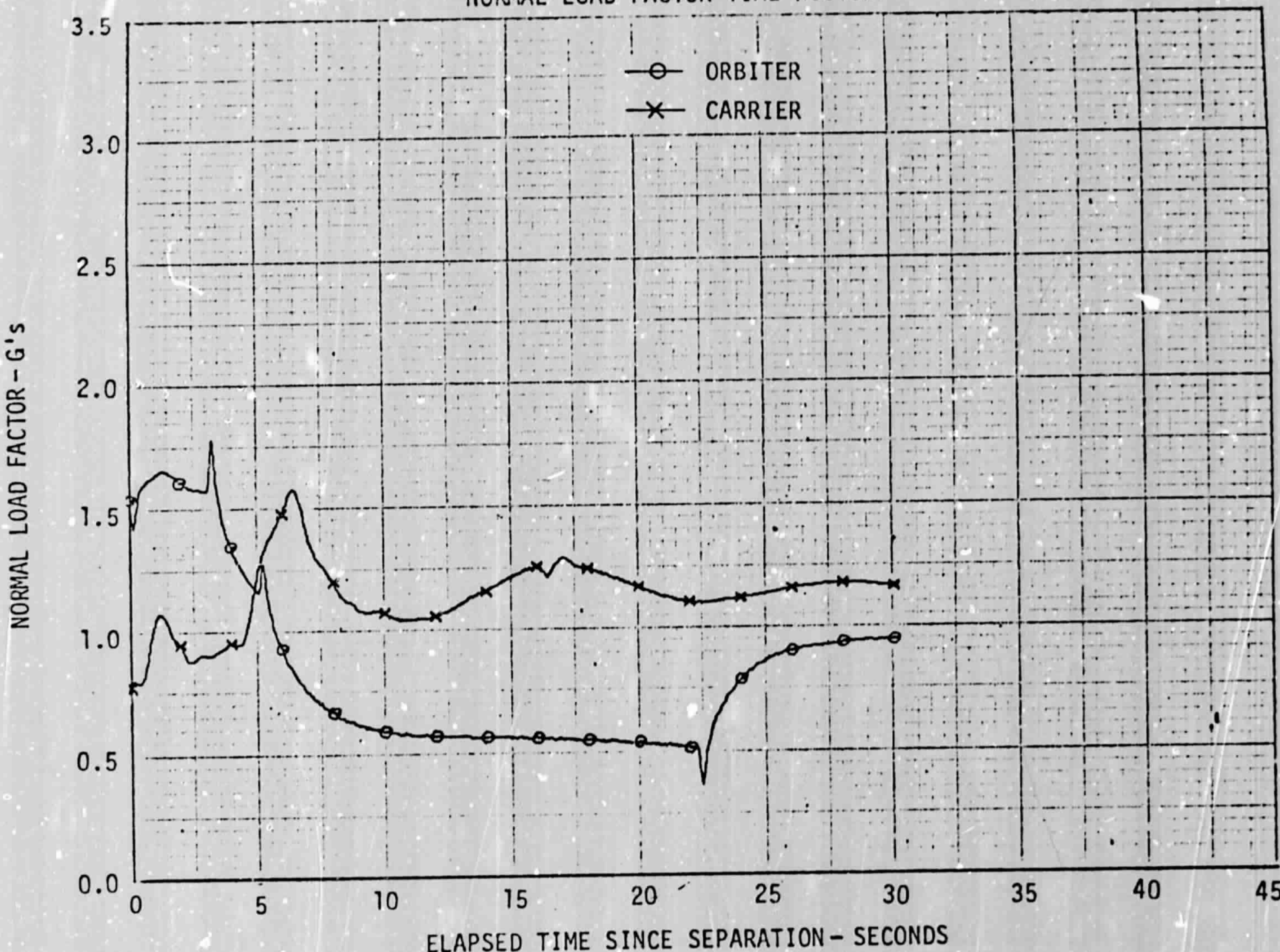

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FIGURE 24
ALT FREE FLIGHT #1 REFERENCE TRAJECTORY
TAILCONE OFF
ORBITER PITCH RATE COMMAND AND RESPONSE TIME HISTORIES

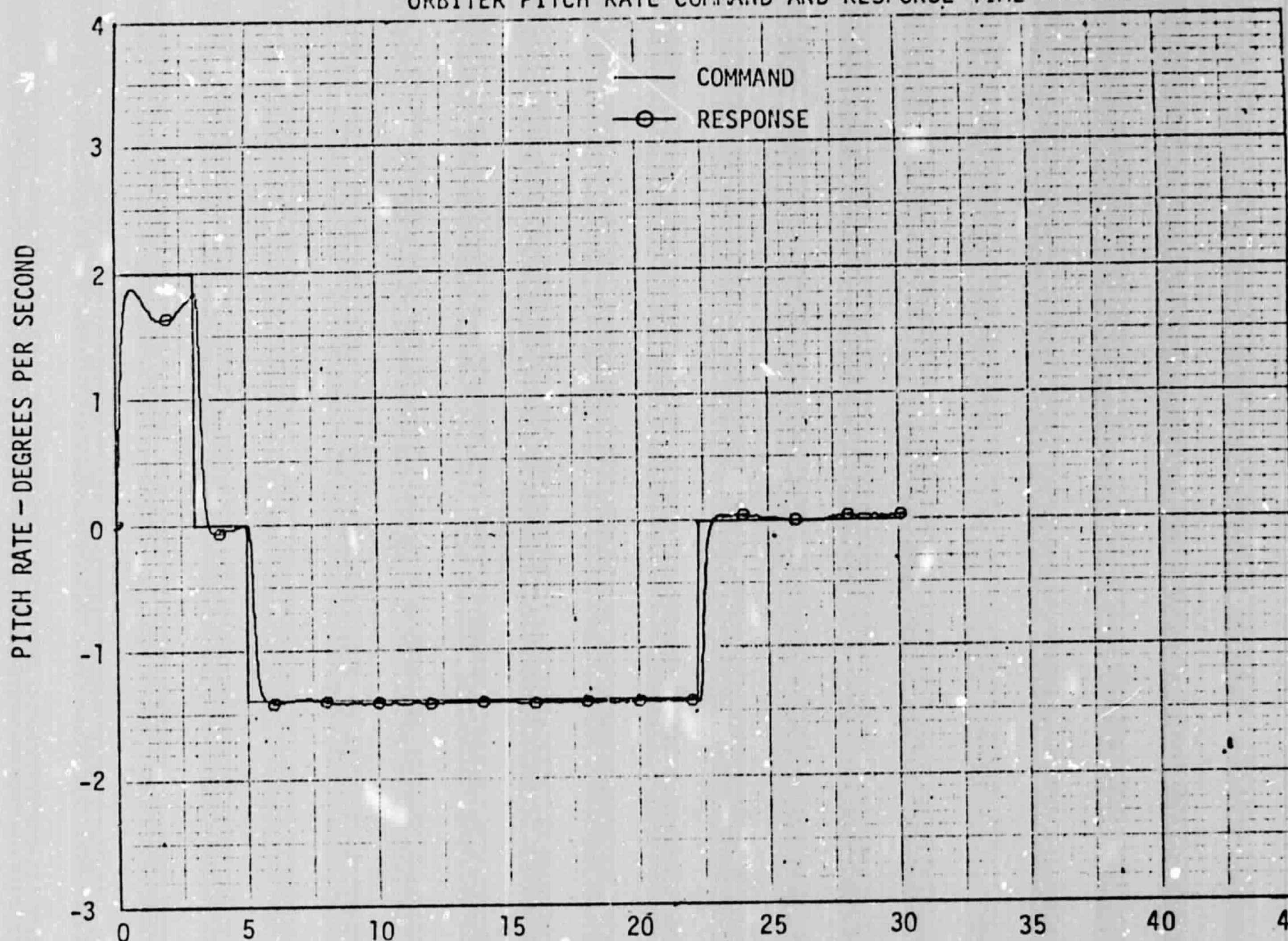

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FIGURE 25

ALT FREE FLIGHT #1 REFERENCE TRAJECTORY

TAILCONE OFF

ANGLE OF ATTACK TIME HISTORY

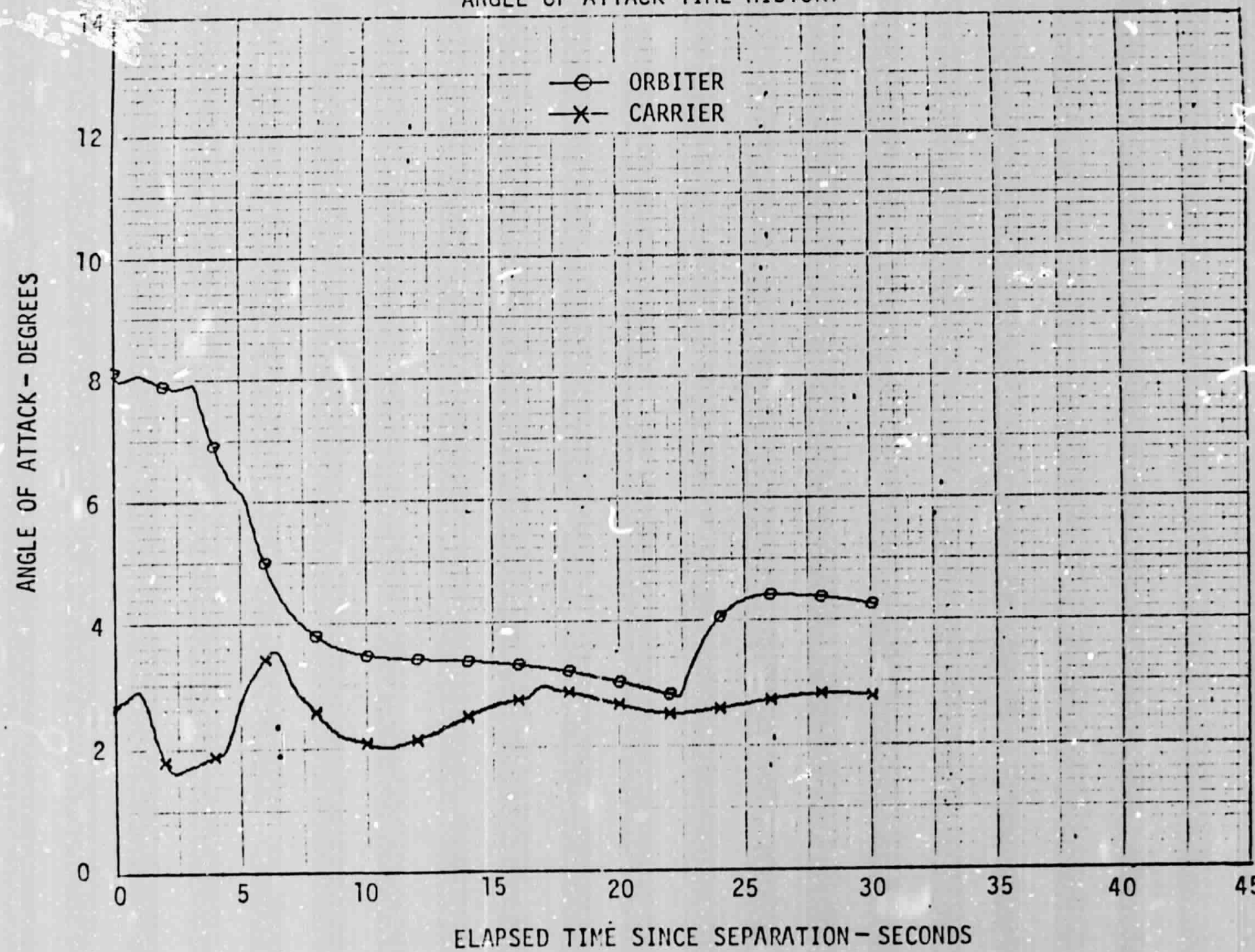

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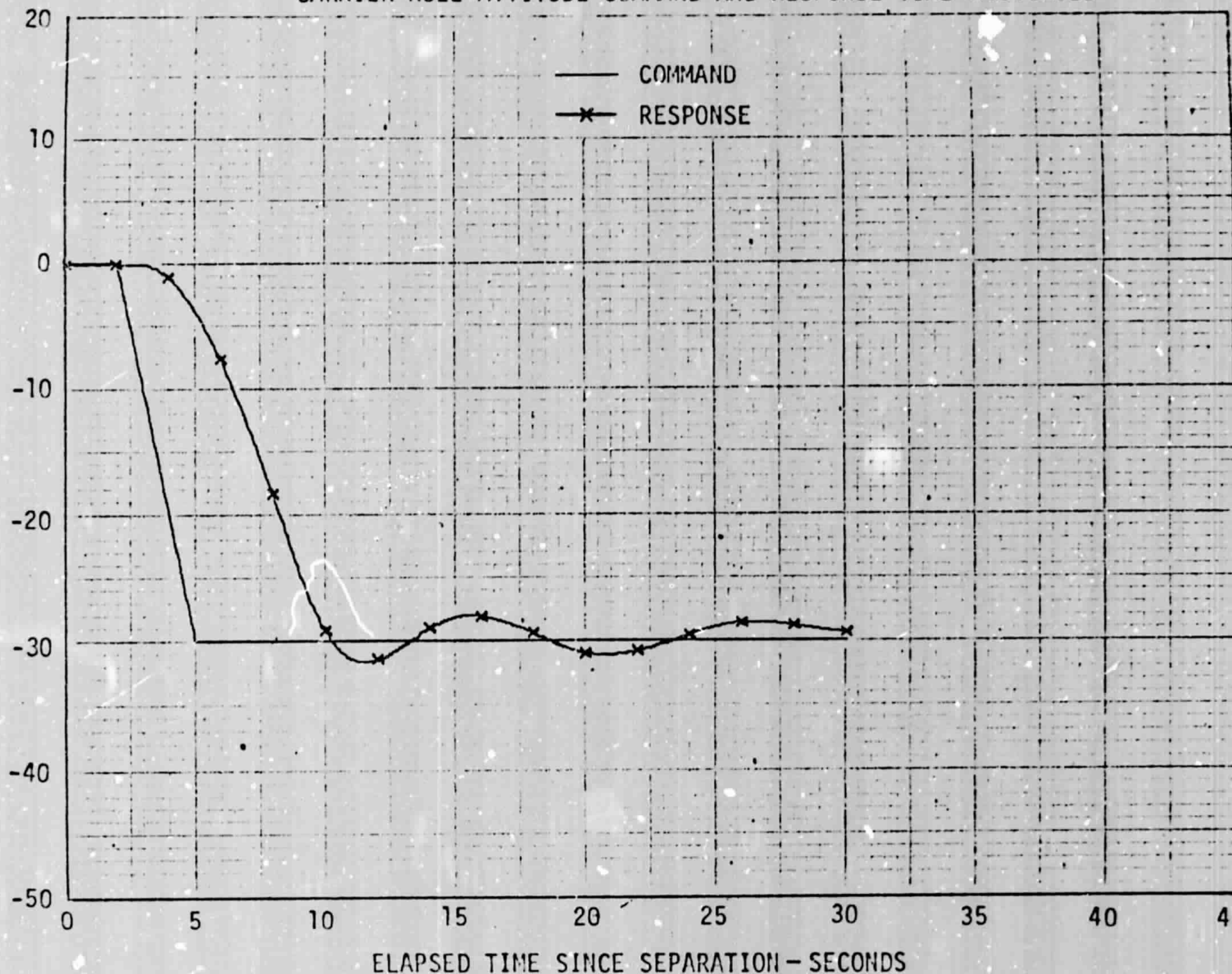
FIGURE 26
ALT FREE FLIGHT #1 REFERENCE TRAJECTORY
TAILCONE OFF
CARRIER ROLL ATTITUDE COMMAND AND RESPONSE TIME HISTORIES



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